Response of coastal Douglas-fir to precommercial thinning on a medium site in British Columbia

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Ministry of Forests
Hon. Tom Waterland
Minister

Canadian Cataloguing in Publication Data

Omule, Stephen Agnew Yen'Emurwon, 1952-
Response of coastal Douglas-fir to precommercial thinning on a medium site in British Columbia

(Research note, ISSN 0226-9368; no. 100)

Bibliography: p.
ISBN 0-7718-8487-7

1. Douglas-fir - British Columbia - Vancouver Island. 2. Forest thinning. I. British Columbia. Ministry of Forests. II. Title. III. Series: Research note (British Columbia. Ministry of Forests); no. 100.

SD397.D7.0482 1985 634.9'75453 C85-092182-1

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Published by the
Information Services Branch
Ministry of Forests
Parliament Buildings
Victoria, B.C.
V8W 3E7

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ABSTRACT

A correlated curve trend (CCT) project, established in 1959 in a 14-year-old Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) plantation on a medium site near Campbell River, British Columbia, was modified in 1966 by adding three replicates (plots) to parts of the spacing and thinning series of the CCT design. The objective of the experiment was to study the effects of various thinning regimes (ranging from no thinning to heavy and frequent thinning) on the growth and yield of coastal Douglas-fir. The experiment consisted of 10 thinning treatments (regimes) with four plots per treatment in a randomized complete block design. The plots have been measured six times at an interval of approximately 4 years. This report presents results and conclusions after a 17-year period.

Stand average and per-hectare values were calculated by plot and measurement period for all trees and for selected (crop) trees, and analyses were done on the basis of individual trees, crop trees, and the entire stand. Analyses indicate that all of the thinning regimes investigated have, to varying degrees, increased the growth of residual trees and produced trees of greater merchantable volume. For example, the gains in individual tree diameter, at total age 38 years, ranged from 9 to 35% and merchantable volume per tree ranged from 65 to 250%, compared to no thinning. It is suggested that dense, young Douglas-fir stands on medium moist, medium rich sites (site index 25 to 33 m at 50 years total age, using Bruce's [1981] site index curves) in the Wetter Maritime Coastal Douglas-fir Subzone in British Columbia should be thinned gradually (similar to treatments F, G, and H) before total age 30 years -- where economically and otherwise feasible -- to a post-thinning density of under 1000 stems per hectare, favouring the largest and healthiest trees for sawlog production. This study is continuing and further remeasurement and analysis will verify and expand the conclusions obtained so far.

ACKNOWLEDGEMENTS

This study was initiated by G.C. Warrack and remeasured and maintained by the late K. Bradley. I thank G.J. Krumlik for providing the soil and vegetation information, D. Spittlehouse for providing the weather records, I.R. Cameron and D. Geils for assistance in data compilation, H. Benskin, D. Errico, K. Iles, W.D. Johnstone, and J.H.G. Smith for reviewing the draft manuscript, and L. Fraser for word processing.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS iv
INTRODUCTION 1
METHODS 1
Study Area 1
Experimental Design 2
Measurements and Summaries 7
Data Analyses 11
Individual tree basis 13
Stand basis and crop-tree basis 14
RESULTS 14
Individual Trees 15
Tree diameter 15
Tree height 19
Entire Stand 19
Stand diameter 19
Stand height 25
Stand basal area 25
Stand total volume 28
Stand merchantable volume 32
Mortality 35
Stand structure 35
Crop Trees 35
Crop-tree diameter 39
Crop-tree height 39
Crop-tree basal area 39
Crop-tree volume 43
DISCUSSION 43
CONCLUSIONS 48
RECOMMENDATIONS 49
LITERATURE CITED 50

TABLES

1 Climate normals (1951-1980) near the study area 3
2 Plot thinning schedules for the original plots 4
3 Plot thinning schedules for the new plots 6
4 Block mean characteristics before the initial (1967) thinning ... 9
5 Thinning treatment individual tree diameter gain over the control of survivor trees at total age 38 years 18
6 Stand parameter gains over the control at total age 38 years 29
7 Treatment average mortality (number of stems and diameter) 37

FIGURES

1 Plot layout in the new plots 8

2 A trivariate graph of tree total volume, height, and diameter 10

3 A graph of merchantable volume factors (MVF) 12

4 Individual tree mean diameter and standard error by treatment and 1967 diameter classes 16

5 Individual tree mean periodic (1967-1983) diameter growth and standard error by treatment and 1967 diameter classes 17

6 Individual tree mean height and standard error by treatment and 1967 diameter classes 20

7 Individual tree mean periodic (1967-1983) height growth and standard error by treatment and 1967 diameter classes 21

8 Four-year height growth of measured survivor trees by treatment and growth period 22

9 Stand arithmetic average diameter and periodic (1967-1983) average diameter growth (with standard errors) by treatment 23

10 Stand diameter development of all trees from total age 21 years . 24

11 Stand arithmetic average height and periodic (1967-1983) average height growth (with standard errors) by treatment 26

12 Stand net basal area, periodic (1967-1983) basal area growth and percentage growth rates (with standard errors) by treatment 27

13 Stand net basal area development of all trees from total age 21 years 30

14 Stand net total volume, periodic (1967-1983) total volume growth, and percentage growth rates (with standard errors) by treatment 31

15 Stand net total volume development of all trees from total age 21 years 33

16 Stand net merchantable volume, periodic (1967-1983) merchantable volume growth, and percentage growth rates (with standard errors) by treatment 34

17 Stand net merchantable volume development of all trees from total age 21 years 36

18 Average diameter distribution in 1967 and in 1983 38

19 Crop-tree arithmetic average diameter and periodic (1967-1983) average diameter growth (with standard errors) by treatment 40

20 Crop-tree arithmetic average height and periodic (1967-1983) average height growth (with standard errors) by treatment 41

21 Crop-tree basal area and periodic (1967-1983) basal area growth (with standard errors) by treatment 42

22 Crop-tree total volume and periodic (1967-1983) total volume growth (with standard errors) by treatment 44

23 Crop-tree merchantable volume and periodic (1967-1983) merchantable volume growth (with standard errors) by treatment 45

APPENDICES

1 Comparison of treatment means for the various individual tree, entire stand and crop-tree characteristics 52

2 A summary of stand and crop-tree characteristics in 1983 (total age 38 years) 56

INTRODUCTION

Thinning is an important tool in the management of forest stands for desired wood products. Thinning promotes rapid growth on residual stems and increases merchantable yields per tree. It also provides early economic returns (from commercial thinning and from shortened rotation, when target diameters are used to define rotation age), and reduces the costs of final harvest and subsequent site preparation. The effects of various (precommercial) thinning regimes were studied within the framework of a Correlated Curve Trend (CCT) thinning experiment, established in 1959 in a 14-year-old Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) plantation on a medium site near Campbell River, British Columbia.

The CCT designs (after O'Connor 1935) essentially consist of a basic set of eight plots (spacing series) achieved by thinning plots from a given initial density -- in advance of competition -- to predetermined densities, and another set of eight or nine plots (thinning series) achieved by subjecting different plots to different degrees of competition before thinning and different degrees of release through thinning. Examples of design and application of CCT studies are available in Bredenkamp (1984) and Omule (1984) and the references therein.

For the present study, parts of the spacing and the thinning series from original plots, which provided a considerable range in thinning regimes, were replicated within the same study area in 1966 (when the plantation was 21 years old). This report presents the results and conclusions to date, 17 years after establishment of the new plots.

METHODS

Study Area

The study area is located 48 km northwest of Campbell River on the east side of Mohun Lake on Vancouver Island (latitude 50° 6' 50" N; longitude 125° 29' 0" W; elevation 260 m). Topography is relatively uniform with a westerly facing slope of 5 to 35°, which is cut by several small creeks. A

few scattered swamps and rock bluffs surround the study area. The soil is well to rapidly drained, medium deep (60-100 cm), sandy orthic humo-feric podzol (Canadian Soil Survey Committee 1978), developed on a sandy morainal glacial blanket. Understory vegetation in the plots is dominated by salal (Gaultheria shallon Pursh.), sword fern (Polystichum munitum (Kaulf.) Presl.), and vanilla leaf (Achlys triphylla (Smith) DC). The area, located in the Wetter Maritime Coastal Douglas-fir Subzone with a soil moisture/nutrient rating ranging from 2/B (very dry/poor) to 5/D (fresh/rich) (Green et al. 1984),[1] was logged in 1941 and burnt (to unknown degree) in 1943. Site index varies between 25 and 33 m at 50 years total age (Bruce 1981).

Weather records are available at the Campbell River B.C. Forest Service (BCFS) weather station (50° 4' N; 125° 19' W; elevation 128 m), which is about 130 m lower in elevation than the study area. At this station, the mean annual temperature is 9°C (mean maximum temperature = 12.9°C; mean minimum temperature 4.9°C) and the total annual precipitation is 1655.6 mm, 19% of which falls in the May to September growing season (Table 1).

The study area is part of a large plantation that was planted in spring 1948 with 2+0 Douglas-fir seedlings raised at the old Campbell River nursery using upper Vancouver Island seed. The seedlings were planted at 5- to 6-ft (1.5- to 1.8-m) square spacing (that is, approximately 3000 to 4300 stems per hectare).

Experimental Design

The original experiment (based on the concept of the CCT design devised by O'Connor [1935]) consisted of 18 plots (Table 2): eight (plots 1-8) constitute the "spacing series" plots representing nominal densities 3000, 1500, 1000, 750, 500, 375, 250, and 125 stems per hectare, respectively; nine (plots 9-16) constitute the thinning series plots, representing different degrees of suppression and different degrees of release; and the remaining two

---

[1] The soil and vegetation descriptions were done by G.J. Krumlik (B.C. Ministry of Forests, Research Branch, 1983).

TABLE 1. Climate normals[a] (1951-1980) near the study area

Climate element[b]	Mean annual	Month										
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Daily maximum temperature (°C)	12.9	3.5	6.4	8.2	12.3	17.0	19.7	22.9	22.4	18.5	12.8	7.1	4.5
Daily minimum temperature (°C)	4.9	-1.2	0.4	0.5	3.3	6.3	9.6	11.4	11.5	9.0	5.8	2.2	0.2
Total precipitation (mm)	1655.6	224.7	189.1	163.0	78.0	62.9	60.2	42.6	67.3	81.6	184.6	230.3	271.3

[a] These climate normals -- the arithmetic mean of the observed values over a 30-year period -- are for the Campbell River BCFS weather station (50° 4' N; 125° 19' W; elev. 128 m).
[b] Daily temperatures are obtained as the arithmetic mean of the daily maximum and minimum temperatures.
Source: Canadian climate normals 1951-1980. British Columbia. Environment Canada, Atmospheric Environment Service, 4905 Dufferin Street, Downsview, Ontario.

TABLE 2. Plot thinning schedules the original plots

Plot no.	Thinning schedule: Year-1946 Age[a]--(2)	1961 (15)	1963 (18)	1965 (20)	1966 (21)	1969 (24)	1974 (29)	1979 (34)	1983 (38)	?	Final post-thinning density	Remarks
	-------- Nominal trees per hectare ----------											
1	3000		----------								3000	Spacing series plots: Gradual thinning according to interval determined by the rate of growth of the thinned plots compared with a similar number of trees in the previous unthinned plot within series
2	3000	1850	1500	----------							1500	
3	3000	1700	1500	1000	----------						1000	
4	3000	1700	1500	1000		750	----------				750	
5	3000	2000	1500	1000		750	500	----------			500	
6	3000	2000	1500	1000		750	500	375	---------		375	
7	3000	1700	1500	1000		750	500	375	250	---	250	
8	3000	1700	1500	1000		750	500	375	250	125	125	
9	3000						1500	1000	500	250	250	Thinning series plots: Several thinning entries
10	3000					1500	1000	500	250	---	250	
11	3000		2000		1500	1000	500	250	---------		250	
12	3000	2000	1000			1000	500	250	---------		250	
13	3000						1000	----------			1000	Thinning series plots: Same degree of suppression with different degrees of release (thinning); a single thinning entry
14	3000						500	----------			500	
15	3000						500	----------			500	Thinning series plots: Different degrees of suppression with the same degree of release (thinning)
16	3000	1240	1000				500	----------			500	
17	3500	----------									3500	Unthinned plots: Replications of plot 1
18	3000	----------									3000	

[a] Ages from seed (in years).

(plots 17 and 18) are "extras", left unthinned as replications of plot 1. The plots are rectangular (with most being square), their areas varying from 0.225 to 0.75 acres (0.091 to 0.303 ha).

Plots 1 to 8 were established in a 14-year-old plantation that had an initial density of approximately 3000 stems per hectare. Gradual thinning in advance of mutual competition reduced these plots to their final respective densities. Plots 9-16, established in the same plantation, were thinned from an initial density of approximately 3000 stems per hectare to various final densities at different ages, usually after the onset of competition. The actual ages at which the thinnings took place are given in Table 2.

At establishment, a "free thinning" was used to balance the gaps and clusters of trees within a plot. Subsequent thinnings removed trees from a range of diameter classes. During each thinning an attempt was made to achieve a uniform nominal spacing of residual trees within a plot, and larger and healthier trees were favoured. The ratio of average diameter of thinned trees to average diameter of trees before thinning ranged from about 0.7 to 1.0. All thinned trees were left on site. The plots had a 15-m wide buffer zone and a distance of at least 30 m maintained between adjacent plots.

As part of another experiment, in 1966 when the trees were 21 years old, parts of the original spacing and thinning series (Table 2) were internally replicated. One replicate, a 0.1-acre (0.0405-ha) square plot, was established within each of the original plots 1, 2, and 9-18. In addition, 28 separate 0.1-acre (0.0405-ha) plots were established within the same study area. Thus, in the new plots there were 10 different thinning treatments (A to J), each replicated four times (Table 3). The main differences between the thinning treatments were in respect to time of first thinning, interval between thinnings, degree of thinning, and final post-thinning density. (Since, throughout the report, the thinning treatments in Table 3 are referenced only by letters A to J, it will be more convenient for the reader to keep a copy of Table 3 handy for comparisons.) The 40 0.1-acre plots were arranged in four blocks (I to IV) (Table 3), each as uniform as could be conveniently achieved in respect of site quality and spatial and diameter frequency distribution of stems. The plots corresponding to treatment A were

TABLE 3. Plot thinning schedules for the new plots

Treatment	Plots within block[a]				Treatment (thinning) schedule[c]							
	I	II	III	IV	Year-----1948 (Age[b])----(2)	1966 (21)	1969 (24)	1974 (29)	1979 (34)	1983 (38)	?	Final post-thinning density
					Nominal density (trees per hectare)							
A	17	18	39	1	3000	----------						3000
B	26	2	34	46	3000	1500	----------					1500
C	19	27	13	45	3000			1000	----------			1000
D	22	33	15	14	3000			500	----------			500
E	25	32	37	42	3000	1500		500	----------			500
F	23	30	16	41	3000	1000		500	----------			500
G	12	28	40	44	3000	1000	500	250	----------			250
H	24	11	36	43	3000	1500	1000	500	250	----------		250
I[d]	21	31	38	10	3000		1500	1000	500	250	------	250
J[d]	20	29	35	9	3000			1500	1000	500	250 -	250

[a] Plot numbers 1-18 correspond to those in Table 2 (the original plots).
[b] Ages from seed (in years).
[c] In 1961, plots 2, 12, and 16 were thinned to 1850, 2000, and 1240 stems per hectare, respectively; in 1963 plots 11 was thinned to 2000 stems per hectare and plots 12 and 16 to 1000 stems per hectare (see Table 2).
[d] These treatments were not analysed in this report.

considered the control. A schematic layout of the plots is shown in Figure 1.

Methods of establishment and determination and conduct of susbsequent thinning used in the new plots were similar to those used in the original plots. The thinning schedules are given in Table 3. In particular, an initial thinning in September 1966 was done to bring the plots as close to the initial nominal densities as possible; the remaining trees within each plot were serially numbered and tagged at breast height (4.5 ft [1.37 m]). The pretreatment data (Table 4) indicated little variation in productivity among plots within each block. From these data it was also evident that the blocks could be arranged in ascending order of productivity as: Block I, Block II, Block III, and Block IV.

Measurements and Summaries

Within each plot, the condition of all the trees, the dbh (diameter at breast height outside bark), and the total height of a subsample of trees (at least 10), were recorded on the following dates: May 1967, October 1969, August 1973, December 1974, December 1978, and June 1983. In all the measurements, dbh was taken at approximately the same height (1.37 m) and total height was taken on the same subsample of trees in each plot. The trees measured for height were subjectively selected, but covered the observed range of diameters in each plot. If a "height tree" was dead or defective (e.g. with a broken or dead top), a replacement tree of approximately the same dbh was chosen. Sometimes, however, neither replacements nor additional trees were measured for height. Measurements prior to 1976 were taken in imperial units and subsequently converted to metric units.

Unmeasured tree heights were estimated from appropriate height-diameter equations fitted separately for each measurement period for each plot. The height-diameter model suggested by Schreuder and Hafley (1977) was used. The total volume (whole stem, inside bark) of each tree was estimated from existing tree volume equations (derived from trees mostly in natural stands) (Figure 2). Merchantable volume, defined as whole stem volume inside bark excluding a 30-cm stump and a 10-cm diameter inside bark top, was estimated for each tree with the use of the appropriate merchantable volume conversion

FIGURE 1. Plot layout in the new plots.

TABLE 4. Block mean characteristics before the initial (1967) thinning

Block	No. of plots[b]	Mean values[a]				
		No. stems (/ha)	Basal area (m^2/ha)	QMD (cm)	Total volume /ha --- (m^3) ---	/tree
I	9	3553(15)	21.0(12)	8.7(5)	84.6(14)	0.0207(18)
II	8	3201(6)	21.8(6)	9.3(5)	91.7(9)	0.0248(30)
III	9	3031(10)	22.8(7)	9.8(3)	100.0(9)	0.0304(22)
IV	10	2750(33)	25.1(9)	10.3(3)	113.5(12)	0.0347(31)

[a] The mean values correspond to the measurements taken in September 1965 (plots 1-18) and July 1966 (plots 19-47); the values in brackets are the coefficients of variation of plot values.

[b] Plots (2, 11, 12, and 16) thinned prior to 1967 were excluded.

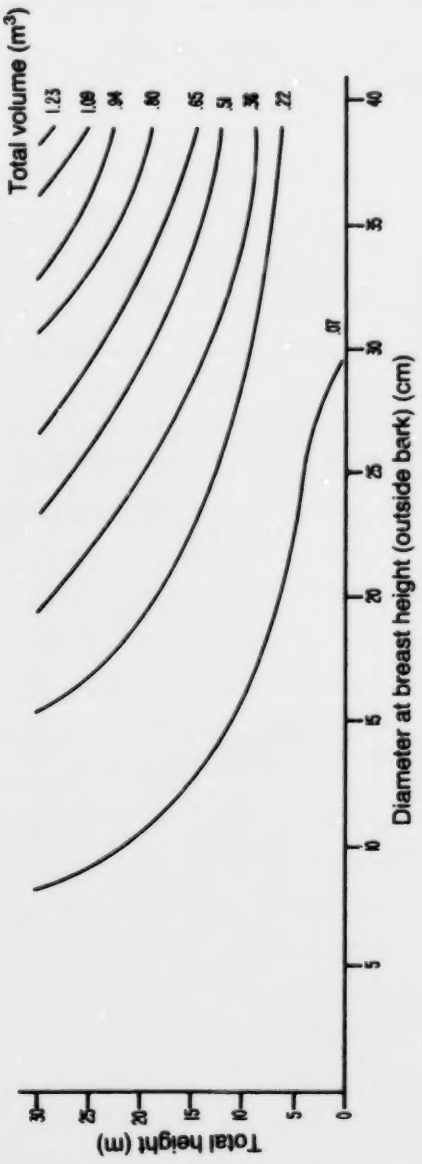

FIGURE 2. A trivariate graph of tree total volume, height, and diameter. These relationships were plotted using equations (1) and (2) contained in Omule (1984, p. 5).

factors from BCFS (1976) (Figure 3). The individual tree measurements were edited and summarized into stand average and per-hectare values per plot at each measurement period, for thinned (cut) trees, mortality (dead) trees, standing (living) trees, net (standing and thinned), and gross (all = thinned + mortality + standing) trees. For each plot, for all trees, the summaries are provided in form of four tables, for each plot:

1. a table of stand average and per-hectare values
2. a stand table, by 5-cm diameter classes
3. a stock table, by 5-cm diameter classes
4. a table of merchantable volumes to various diameter limits.

For crop trees -- those trees ear-marked for final harvest, only the stand average values were summarized.[2] The crop-tree summaries were obtained for each plot from eight trees chosen on the basis of largest present (1983) dbh and then traced back through the remeasurement periods.

In addition, net and gross periodic growth and growth rates of stand basal area, total and merchantable volumes were calculated for each plot. Net values are those of standing plus thinned trees (i.e., excluding mortality). The percentage growth rates were calculated in terms of compound interest (Husch et al. 1972, p. 304).

Data Analyses

Various increment and yield statistics were compared among the thinning treatments, with the use of the methods of analysis of variance (or covariance). The analyses, done separately on the basis of individual trees, entire stand, and crop trees, were restricted to the data from plots corresponding to treatments A to H. (Treatment I was only recently completed and treatment J has yet to be completed; see Table 3.) Furthermore, the data from plots 2, 11, 12, and 16, corresponding to treatments B, H, G, and F,

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2 The summaries are provided in the 1984 report "A progress report on E.P. 554.02: A correlated curve trend experiment in a pure, even-aged plantation of Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco] on a medium site on Vancouver Island", by Stephen A.Y. Omule, B.C. Ministry of Forests, Victoria, B.C.

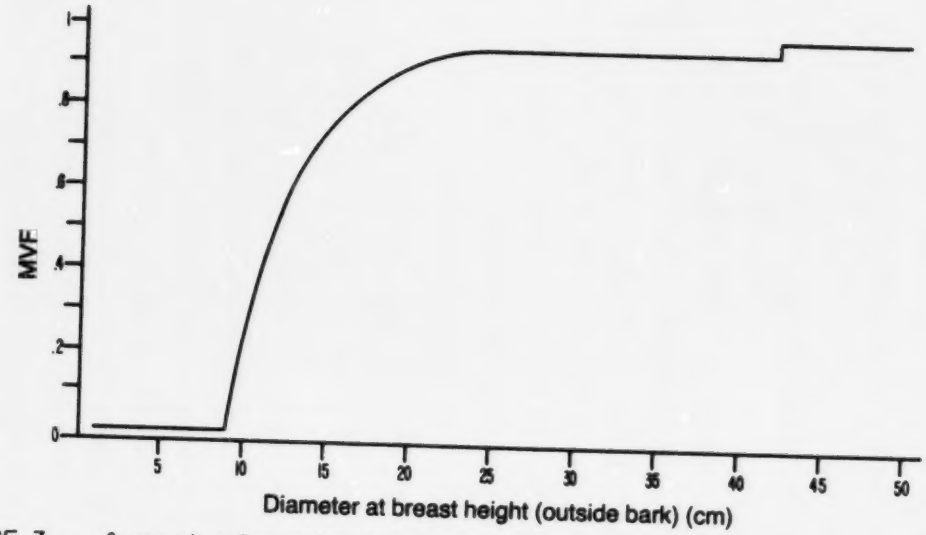

FIGURE 3. A graph of merchantable volume factors (MVF). This graph was plotted using equations in Omule (1984, p. 6). Merch. volume = Total volume x MVF.

respectively, were excluded from the analyses since these plots had been thinned to under 3000 stems per hectare (Table 1) prior to the establishment of the new plots in 1966. Treatment A, the set of the unthinned plots, will be considered the "control" for the study.

Individual tree basis

For each plot, individual tree diameters in 1967, 1978, and 1983 were obtained from measurement records of those trees that survived the growth period 1967-1983. Periodic diameter growth was calculated for each survivor tree for the periods 1967-1983 and 1978-1983 (the overall and current growth periods, respectively). The survivor trees were sorted into 2-cm (1967) diameter classes, for each plot. Then, for each diameter class common to all the treatments, the individual tree diameter in 1983 and the periodic diameter growth in 1967-1983 and 1978-1983 were compared among the thinning treatments A to H. To adjust for site differences between trees, analysis of covariance in a completely randomized design was used; the covariate was the 1967 individual tree diameter. When the treatment effects were detectable ($p = .05$), the adjusted treatment means (means adjusted for the covariate) were separated by repeated t-tests of all combinations of thinning treatments, taken two at a time. (The word "detectable" is used in this report to mean statistically "significant".) In addition, the gains of the various thinning treatments, compared to the control, were determined by diameter classes. The gains were calculated as the difference (in 1983) between the mean diameter of a given treatment and the mean diameter of the control, expressed as a percentage of the latter.

In a similar manner, the individual tree heights and periodic tree height growth were obtained and compared among the thinning treatments. The trees used in the height comparisons were those actually measured for total height from 1967 through 1983. The covariate used was the 1967 individual tree height.

Stand basis and crop-tree basis

Stand average and per-hectare values for all the trees in the plot and for crop trees were compared among thinning treatments A to H using a randomized complete block design analysis of variance. The design was unbalanced since plots 2, 11, 12, and 16 were excluded from the analyses. The entire stand responses (characteristics) compared were:

1. arithmetic average and quadratic mean diameters (in 1967 and 1983, and periodic growth in 1967-1983);
2. arithmetic average height (in 1967 and 1983, and periodic growth in 1967-1983);
3. stand basal area, total volume, and merchantable volume (in 1967 and 1983 net and gross periodic growth in 1967-1983, and net and gross percentage growth rates in 1967-1983 and 1978-1983);
4. per tree basal area, total volume, and merchantable volume (in 1967 and 1983 and period growth in 1967-1983); and
5. cumulative mortality in 1983.

Similar responses (excluding growth rates and per-tree characteristics) were compared for the crop trees. When the treatment effects were detectable ($p = .05$), the treatment means were separated by Tukey's test. In addition, the gains of the thinning treatments, compared to the control in terms of the various entire stand parameters in 1983, were determined (as was done for individual-tree diameters).

Because of the small plot sizes and hence few (10-110) trees per plot, especially in the heavily thinned plots, comparisons of tree diameter or height distributions among the treatments were not carried out. However, since differences in stand structure were apparent, to give a rough idea of these differences among the treatments, current (1983) dbh standard deviations were calculated for each plot, using the survivor trees.

RESULTS

The original CCT project was modified by adding replicates (plots) to parts of the spacing and the thinning series. Thus it was possible to

statistically verify gains from some of the thinning regimes (treatments). Yield and increment statistics obtained from data collected over a 17-year period were analysed by the methods of analysis of variance. The results are given separately on the basis of individual trees, the entire stand, and crop trees. Details of the statistical comparisons of treatment means for the various individual tree, entire stand, and crop-tree characteristics are given in Appendix 1. A summary of the entire stand and crop-tree characteristics in 1983 by treatment is given in Appendix 2.

Individual Trees

Tree diameter

Comparison of present (1983) individual tree diameter (Figure 4) and periodic diameter growth in 1967-1983 (Figure 5) among thinning treatments A to H indicated that:

1. for initial (1967) diameter classes of 10, 12, and 14-cm, the present diameters and diameter growth were detectably larger in the thinned plots, than in the control plots. Moreover, there were detectable differences in diameter and diameter growth (for each diameter class) among thinned plots, of different final post-thinning densities. For the initial 16-cm diameter class (the highest common diameter class), however, there were no detectable differences in diameter and diameter growth between the control and the thinned plots. If differences really do exist in present diameter (diameter growth) in the 16-cm diameter class, they would be in the range of 9 to 27% (-5 to 71%).
2. in all the treatments, present diameters and diameter growth increased with increasing initial diameter classes (10 to 16-cm).
3. for a given diameter class, the gain over the control in diameter was higher in the more heavily or more frequently thinned plots. In each treatment, however, the gains decreased in larger diameter classes (Table 5).

These results indicate that precommercial thinning has an important effect on the diameter and periodic diameter growth of smaller trees. It, however, has to date no significant effect on larger trees.

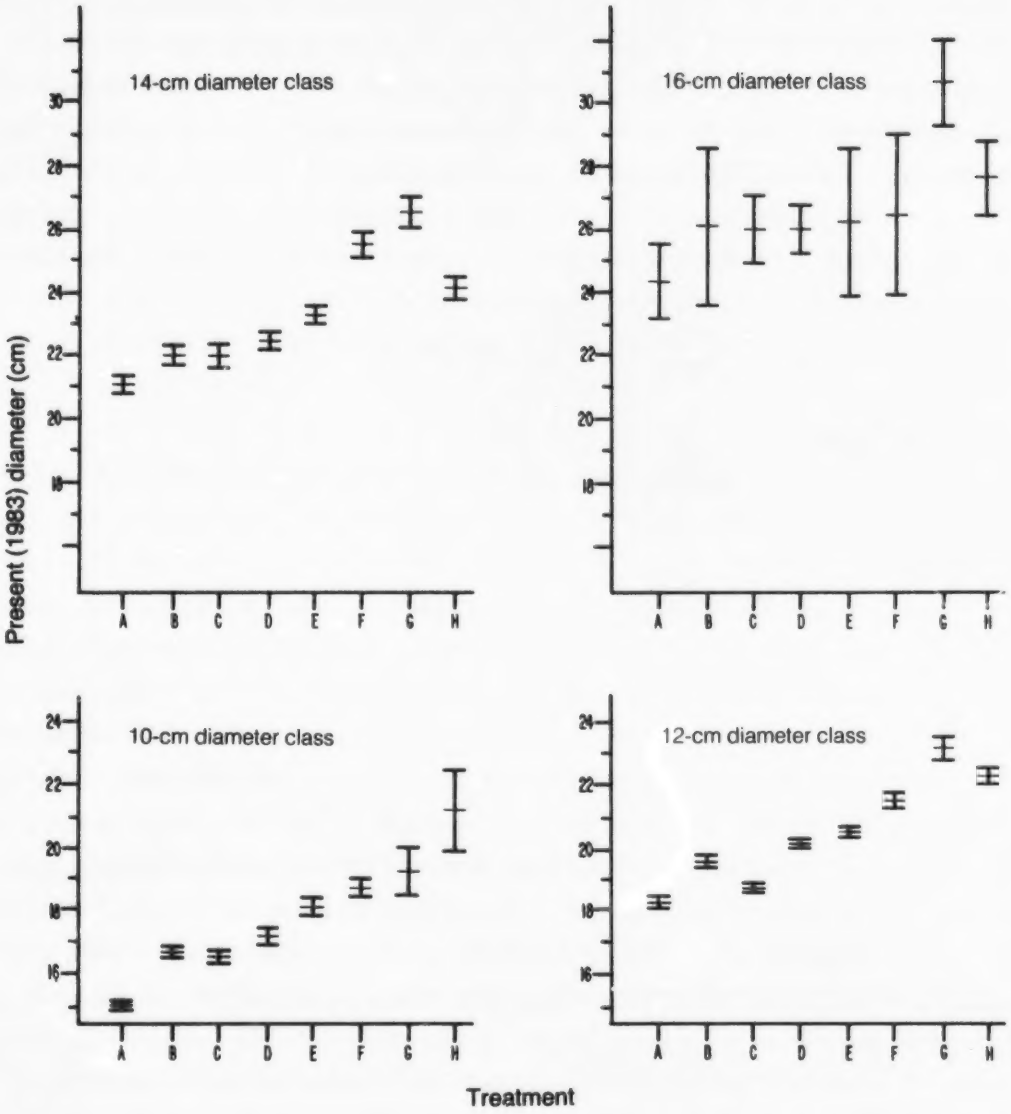

FIGURE 4. Individual tree mean diameter and standard error by treatment and 1967 diameter classes. Each observation is represented as a vertical line segment with the mean at the centre bounded by one standard error.

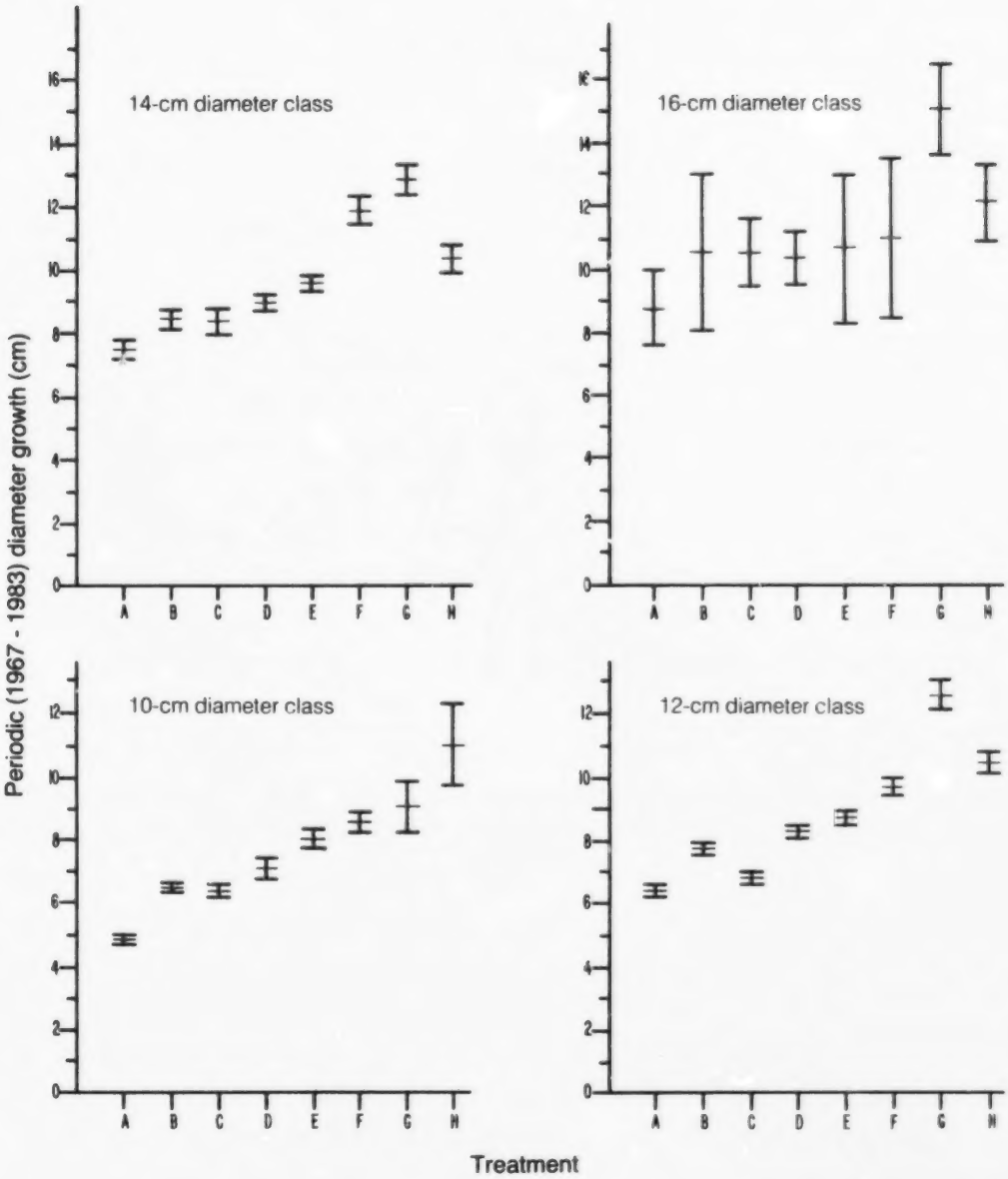

FIGURE 5. Individual tree mean periodic (1967-1983) diameter growth and standard error by treatment and 1967 diameter classes. Each observation is represented as a vertical line segment with the mean at the centre bounded by one standard error.

TABLE 5. Thinning treatment individual tree diameter gain over the control of survivor trees at total age 38 years

Treatment	Gain in diameter (% above control)					
	Diameter class (cm)					
	8	10	12	14	16	All diameter classes
A[a]	0	0	0	0	0	0
B	11	11	7	4	7	9
C	16	10	2	4	7	7
D		14	11	6	7	12
E		21	13	10	8	15
F		25	18	20	9	22
G		28	35	25	26	35
H		40	22	14	14	23

[a] The absolute control values were: 11.7, 14.9, 18.3, 21.1, 24.2, and 14.9 cm for diameter classes 8 to 16-cm and all classes, respectively.

Tree height

Comparison of present (1983) individual tree height and periodic height growth in 1967-1983 indicated that for initial (1967) diameter classes of 10, 12, 14, and 16-cm, the present height and periodic height growth in 1967-1983 were not detectably different between the control and the thinned plots (Figures 6 and 7). If differences really do exist in present height (height growth), they would be in the range of -8 to 6% (-22 to 4%), -13 to 3% (-18 to 5%), -3 to 5% (-19 to 4%), and -7 to 3% (-10 to 23%), for the diameter classes 10, 12, 14, and 16-cm, respectively.

Trends in average periodic height growth of all measured survivor "height" trees (Figure 8) indicated that prior to the 1974 thinning the height growth (in 1969-1973) was identical among the treatments A to H. Immediately following thinning, however, the height growth declined in all the treatments, with a magnitude in decline roughly proportional to the thinning intensity and the density just before thinning. In the period 1978-1983, the height growth increased in all the treatments except the control (which continued to decline).

These results indicate that although precommercial thinning has no important effect on individual tree height to date and height growth in 1967-1983, it does cause noticeable reductions in height growth -- "thinning stock" effects (Staebler 1956) -- in the periods immediately following thinning.

Entire Stand

Stand diameter

The present (1983) arithmetic average diameter (AAD) and periodic AAD growth in 1967-1983 were detectably higher in the thinned plots than in the control plots, and there were detectable differences among thinned plots of different final post-thinning densities (Figure 9). The more heavily thinned and more gradually thinned plots had larger average diameters and greater diameter growth (Figure 10).

The results of the comparisons of quadratic mean diameter (QMD) were the same as those described for AAD.

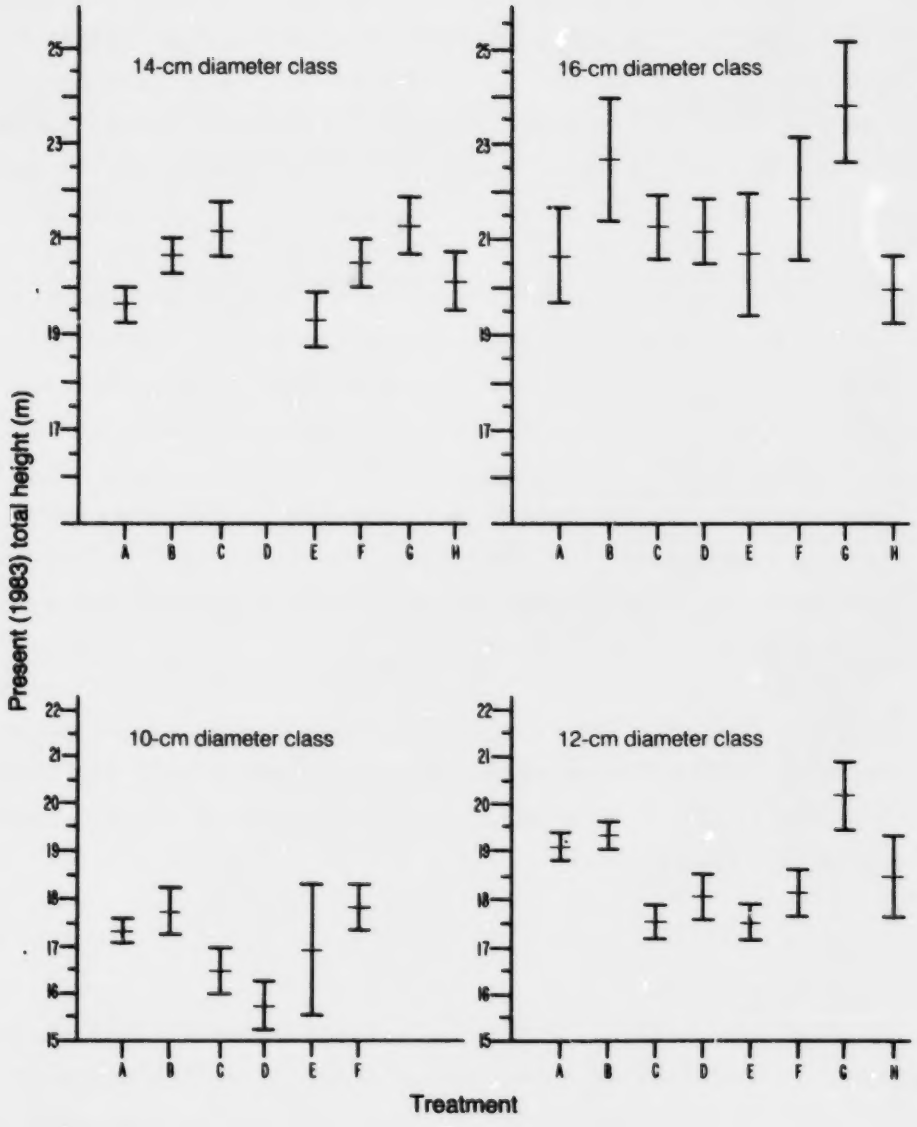

FIGURE 6. Individual tree mean height and standard error by treatment and 1967 diameter classes. Each observation is represented as a vertical line segment with the mean at the centre bounded by one standard error.

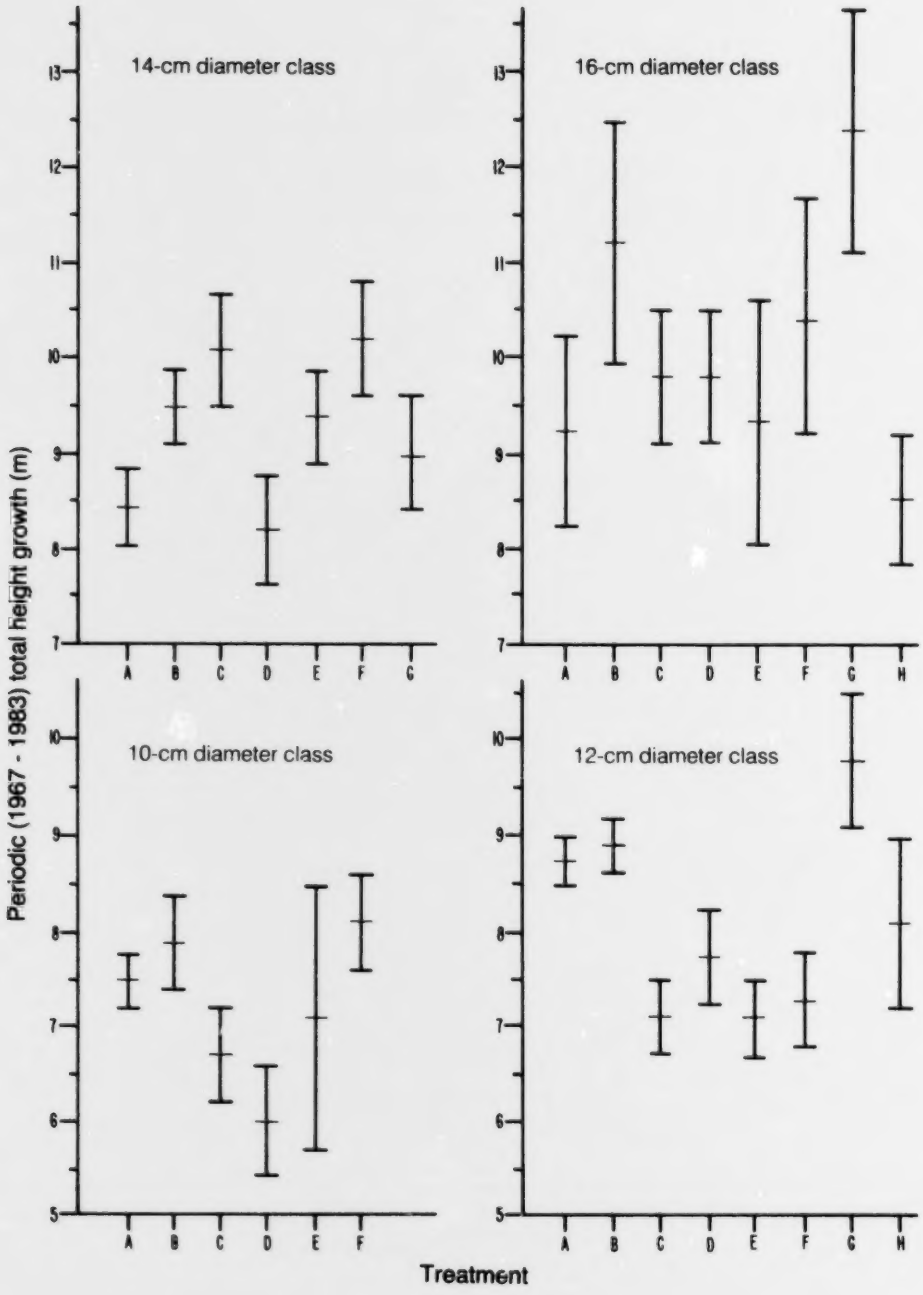

FIGURE 7. Individual tree mean periodic (1967-1983) height growth and standard error by treatment and 1967 diameter classes. Each observation is represented as a vertical line segment with the mean at the centre bounded by one standard error.

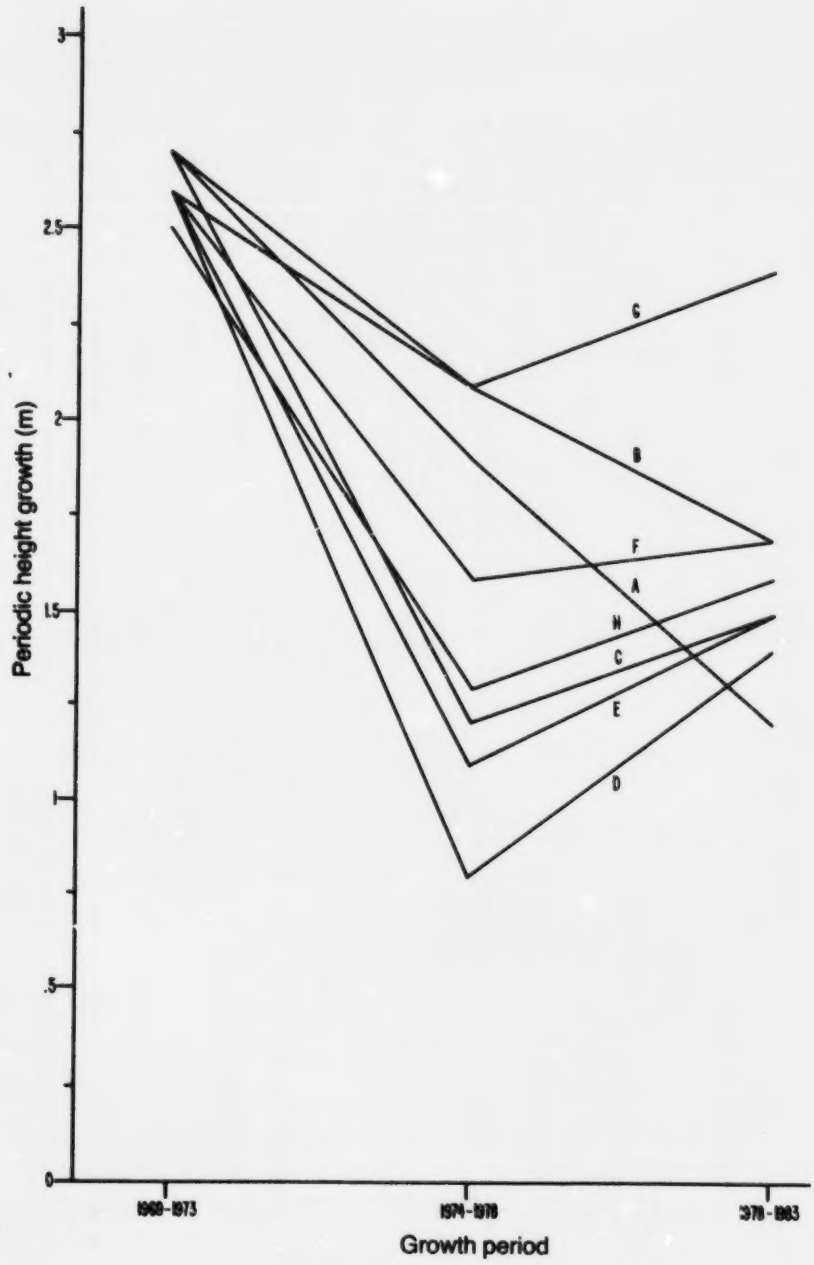

FIGURE 8. Four-year height growth of measured survivor trees by treatment and growth period. Height growth was adjusted by covariance analysis using the 1967 height as the covariate.

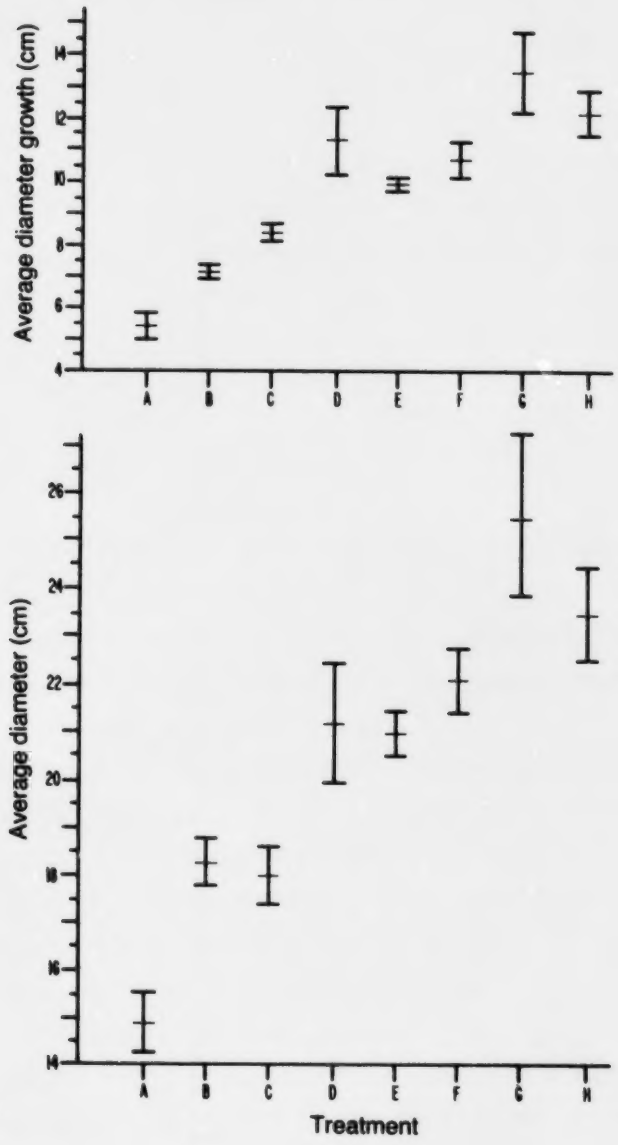

FIGURE 9. Stand arithmetic average diameter and periodic (1967-1983) average diameter growth (with standard errors) by treatment. Each observation is represented as a vertical line segment with the mean at the centre bounded by one standard error.

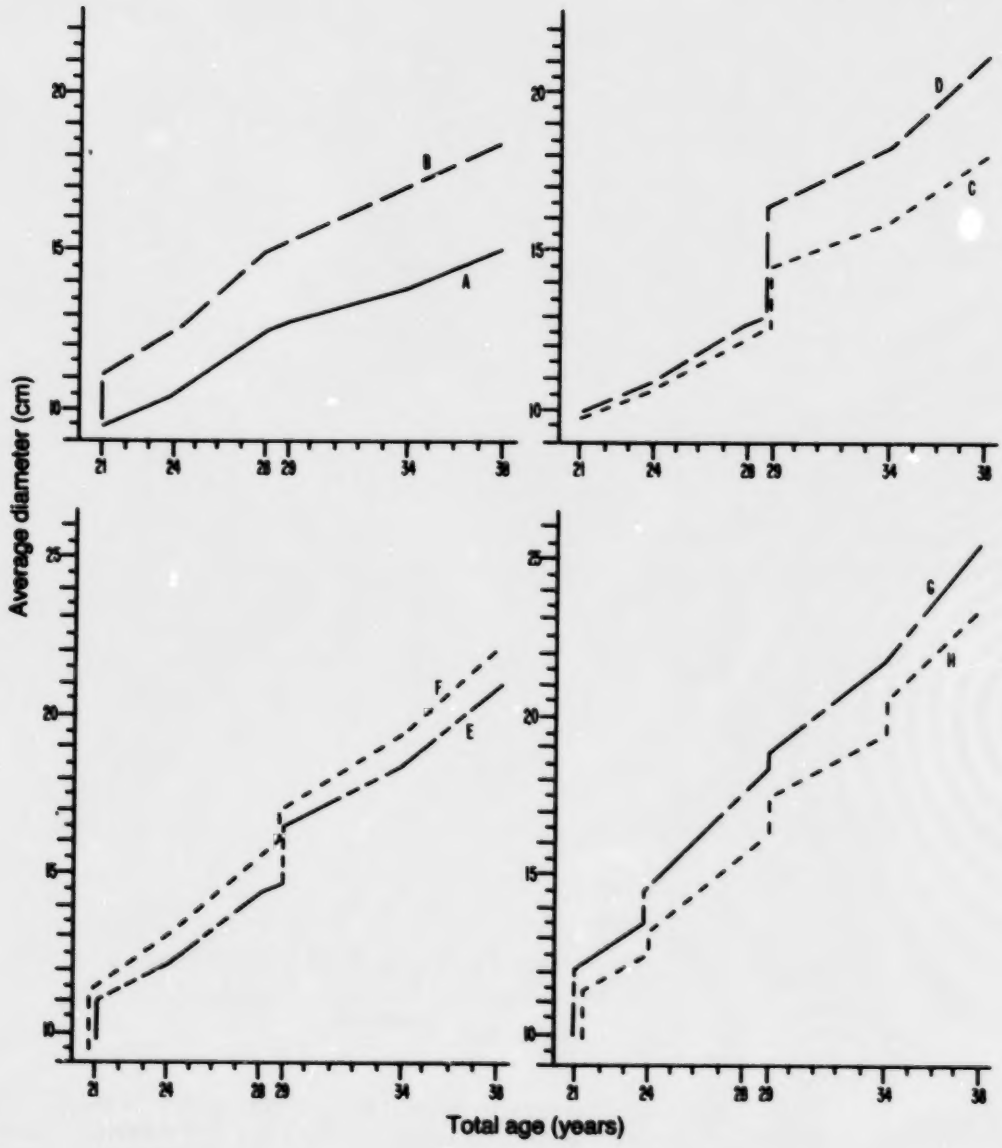

FIGURE 10. Stand diameter development of all trees from total age 21 years.

These results indicate that precommercial thinning has an important effect on stand diameter and diameter growth.

Stand height

There were no detectable differences in arithmetic average height (AAH) in 1983 and periodic AAH growth in 1967-1983 between the control and the thinned plots (except in treatment G, which had detectably higher AAH in 1983) (Figure 11). If differences really do exist in present AAH (AAH growth), they would be in the range of 1 to 15% (-1 to 16%).

These results indicate that, within limits, there is no important effect on stand height or height growth from thinning stands in the ways described here.

Stand basal area

Comparison of the treatment means for the various measures of stand basal area response indicated that (Figure 12):

1. There were detectable differences in present standing basal area per hectare between the control and the thinned plots (except treatment B, which was not detectably different).
2. The net (standing plus thinned) periodic basal area growth in 1967-1983 was not detectably different between the control and the thinned plots (except treatment G, which was detectably lower). If differences really do exist in net basal area growth, they would be in the range of -19 to 13%. However, gross periodic basal area growth in the control plots and those plots thinned only once (treatments B to D) was detectably higher than that of the more gradually thinned plots (treatments E to H). This difference between net and gross basal area growth is due to the heavier mortality in the control and less heavily thinned plots.
3. The percentage net basal area per hectare growth rates in 1978-1983 were detectably lower in the control than the thinned plots (except treatment B, which was not detectably different). There were no detectable differences in the growth rates among the more heavily thinned plots (treatments D to H).

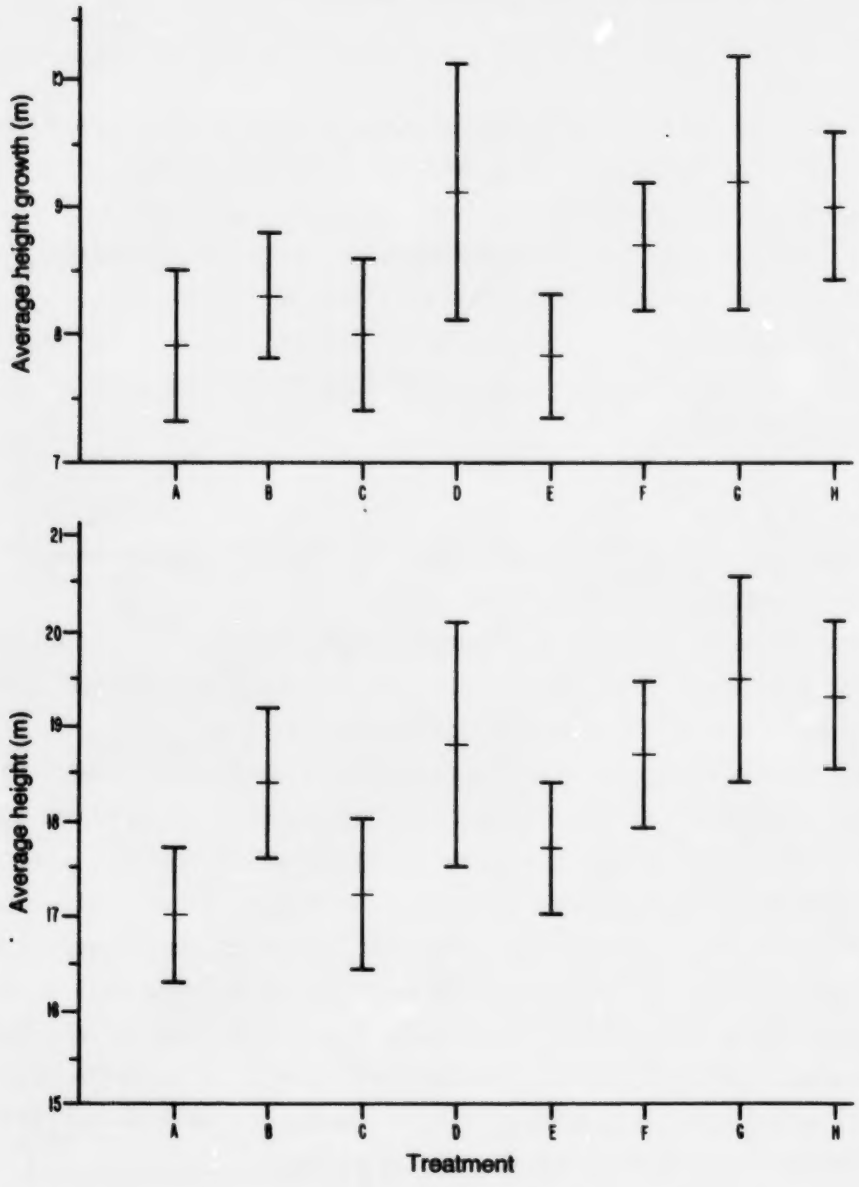

FIGURE 11. Stand arithmetic average height and periodic (1967-1983) average height growth (with standard errors) by treatment. Each observation is represented as a vertical line segment with the mean at the center bounded by one standard error.

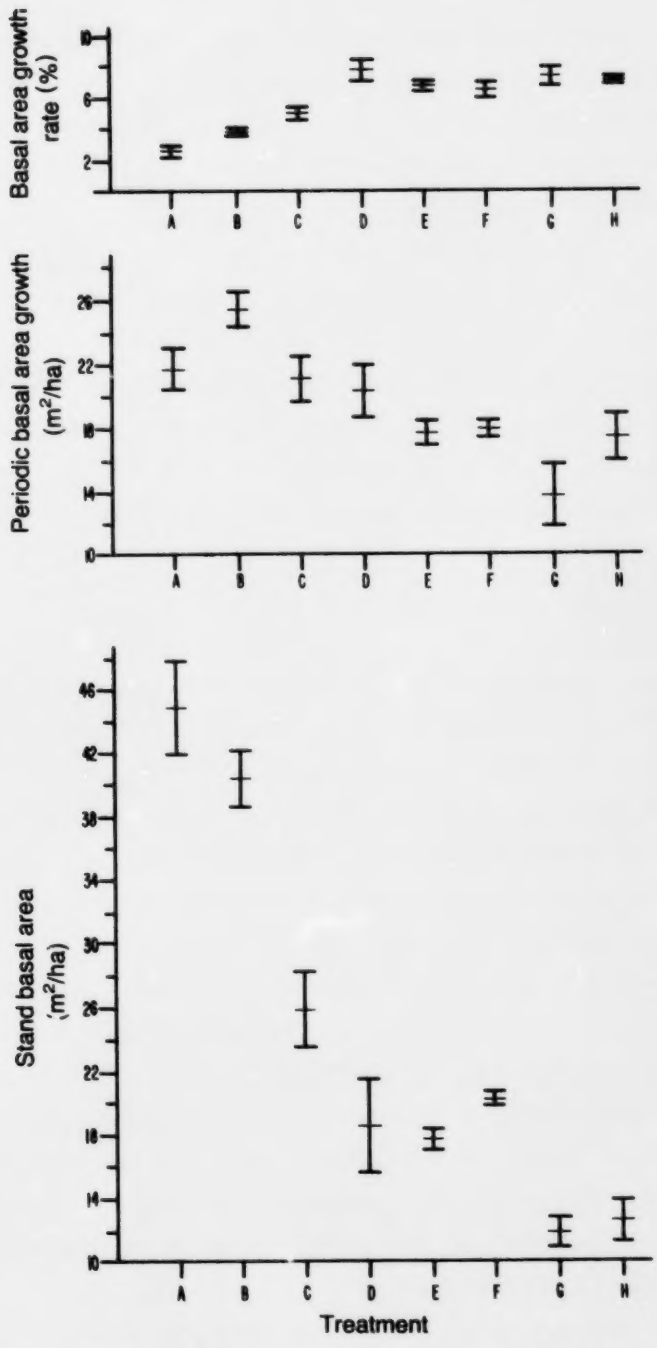

FIGURE 12. Stand net basal area, periodic (1967-1983) basal area growth, and percentage growth rates (with standard errors) by treatment. The percentage growth rates are based on compound interest rates for the period 1978-1983. Each observation is represented as a vertical line segment with the mean at the centre bounded by one standard error.

4. The results of the comparisons of present average basal area per tree are similar to those of stand diameter. The present average basal area per tree in the control plots and the less heavily thinned plots (treatments B and C) was detectably lower than in the more heavily thinned plots (treatments D to H).

A summary of the gains over the control in basal area through thinning is given in Table 6.

These results (1 to 4 above) indicate that although precommercial thinning increases the average basal area per tree (by "shifting" growth to the remaining trees), this increase has not been great enough to offset the decrease in initial growing stock caused by thinning. Thus, the basal area in the thinned plots continues to lag behind that in the control plots (Figure 13).

Stand total volume

Comparisons of the treatment means for various measures of stand total volume (whole stem, inside bark) response were generally similar to those for stand basal area; they indicated that (Figure 14):

1. There were detectable differences in present standing total volume per hectare between the control and the thinned plots (except treatment B, which was not detectably different).
2. For both net and gross periodic total volume growth in 1967-1983, the control plots and those plots thinned only once (treatments B to D) had detectably higher growth than the more heavily and the more gradually thinned plots (treatments E to H).
3. The percentage net total volume per hectare growth rates in 1978-1983 were detectably lower in the control than the thinned plots (except treatment B, which was not detectably different). There were no detectable differences in the growth rates among the more heavily thinned plots (treatments D to H).
4. The present average total volume per tree was detectably lower in the control plots and the less heavily thinned plots (treatments B and C) than in the more heavily thinned plots (treatments D to H).

TABLE 6. Stand parameter gains over the control at total age 38 years

Treatment no.	Gain in parameter (% above control)								
	Net total volume			Net basal area			Net merch. volume		
	/ha	/tree	growth/ha[a]	/ha	/tree	growth/ha	/ha	/tree	growth/ha
A[b]	0	0	0	0	0	0	0	0	0
B	-8	48	37	-10	44	43	3	66	14
C	-45	34	56	-43	41	93	-38	49	41
D	-57	98	129	-59	95	201	-49	134	84
E	-62	79	94	-60	88	156	-55	111	55
F	-55	107	90	-55	111	136	-46	152	51
G	-68	186	129	-69	181	184	-61	250	71
H	-71	143	119	-72	138	181	-65	190	67

a Percent growth rate, based on compound interest (1978-83).
b The absolute values for the control were: 338.3 m^2/ha, 0.14 m^3, and 4.3% for volume; 44.9 m^2/ha, 0.02 m^2 and 2.6% for basal area; and 259.5 m^3/ha, 0.11 m^3, and 6.2% for merchantable volume.

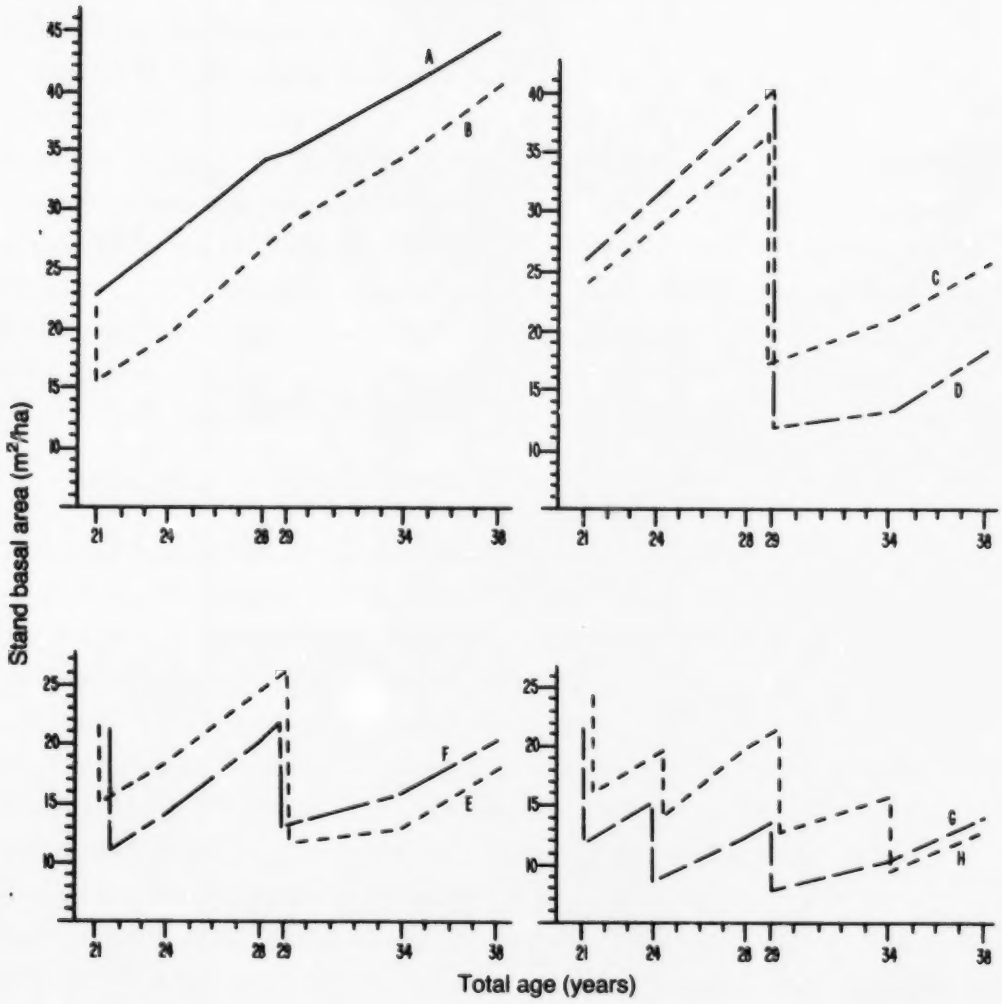

FIGURE 13. Stand net basal area development of all trees from total age 21 years.

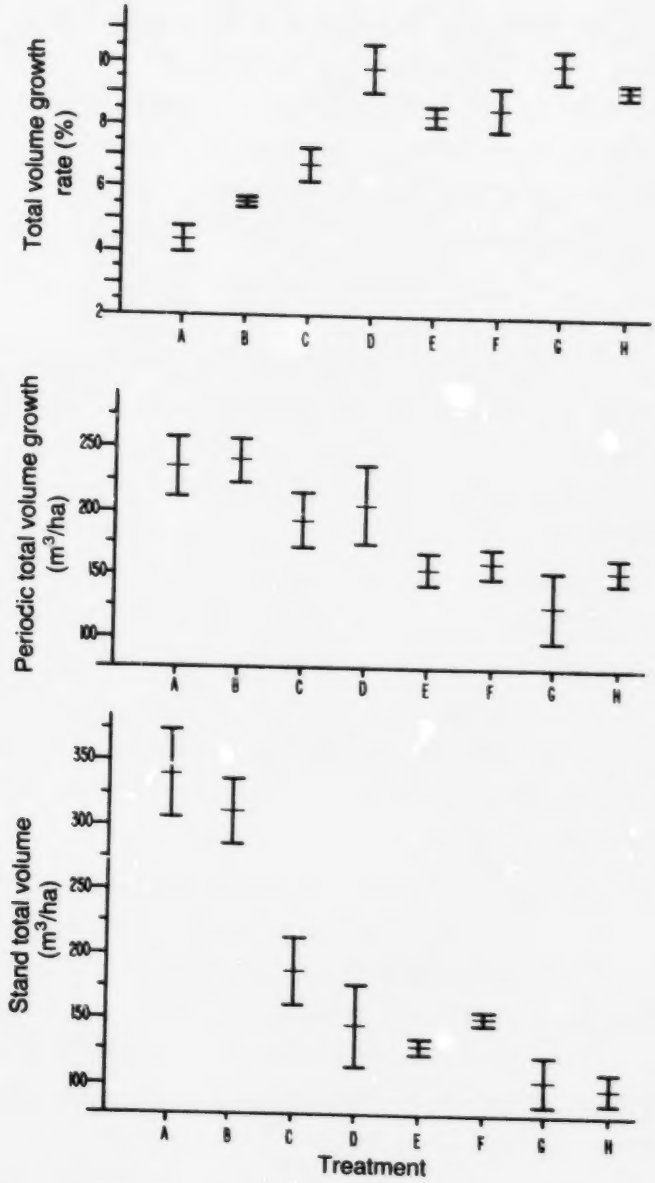

FIGURE 14. Stand net total volume periodic (1967-1983) total volume growth, and percentage growth rates (with standard errors) by treatment. The percentage growth rates are based on compound interest rates for the period 1978-1983. Each observation is represented as a vertical line segment with the mean at the centre bounded by one standard error.

A summary of the gains over the control in total volume through thinning is given in Table 6.

These results (1 to 4 above) indicate that although precommercial thinning increases the average total volume per tree, this increase has not been great enough to offset the decrease in initial growing stock caused by thinning. Thus the total volume per hectare on the thinned plots continues to lag behind that in the control plots (Figure 15).

Stand merchantable volume

Comparisons of the treatment means for the various measures of stand merchantable volume (whole stem volume less a 30-cm stump and a 10-cm diameter inside bark top) response showed that (Figure 16):

1. There were detectable differences in standing merchantable volume per hectare between the control and the thinned plots (except treatment B, which was the same), but there were no detectable differences among the thinned plots. In terms of 1983 net merchantable volume (standing plus thinned), the control and thinned plots (except treatments E and G, which were detectably lower) were not detectably different. The merchantable volume in the control plots, was however, concentrated in the smaller diameter classes (10- to 25-cm diameter classes versus 25- to 30-cm diameter classes).
2. For both net and gross periodic merchantable volume growth in 1967-1983, the control plots and those plots thinned only once (treatments B to D) had detectably higher growth than the more heavily and more gradually thinned plots. The growth rates for 1978-83 were detectably higher in the thinned than the control plots.
3. The present average merchantable volume per tree was detectably lower in the control and the less-heavily thinned plots (treatments B and C) than in the more-heavily thinned plots (treatments G and H).

A summary of the gains over the control in merchantable volume through thinning is given in Table 6.

These results (1 to 3 above) indicate that although precommercial thinning increases the average merchantable volume per tree, this increase

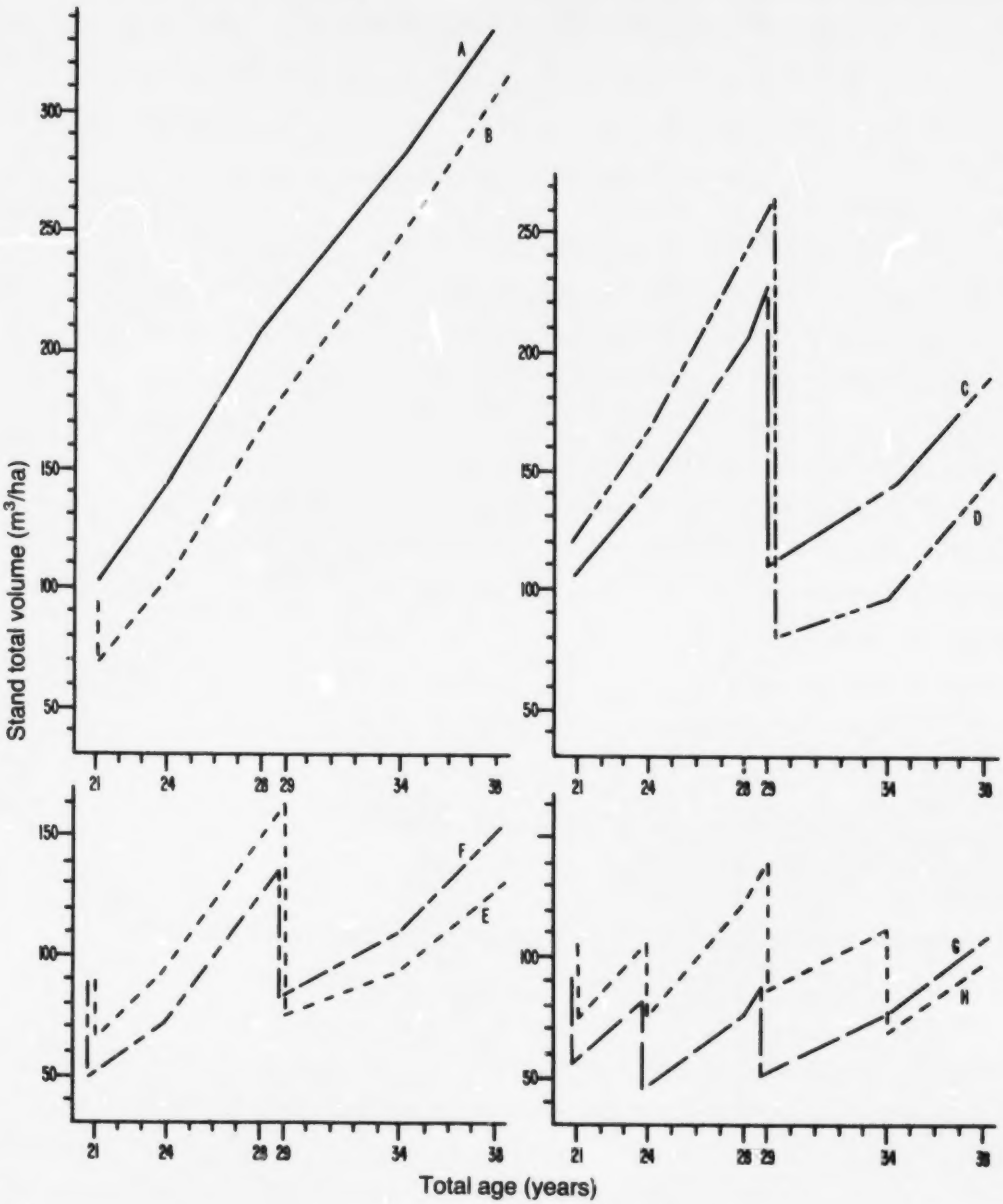

FIGURE 15. Stand net total volume development of all trees from total age 21 years.

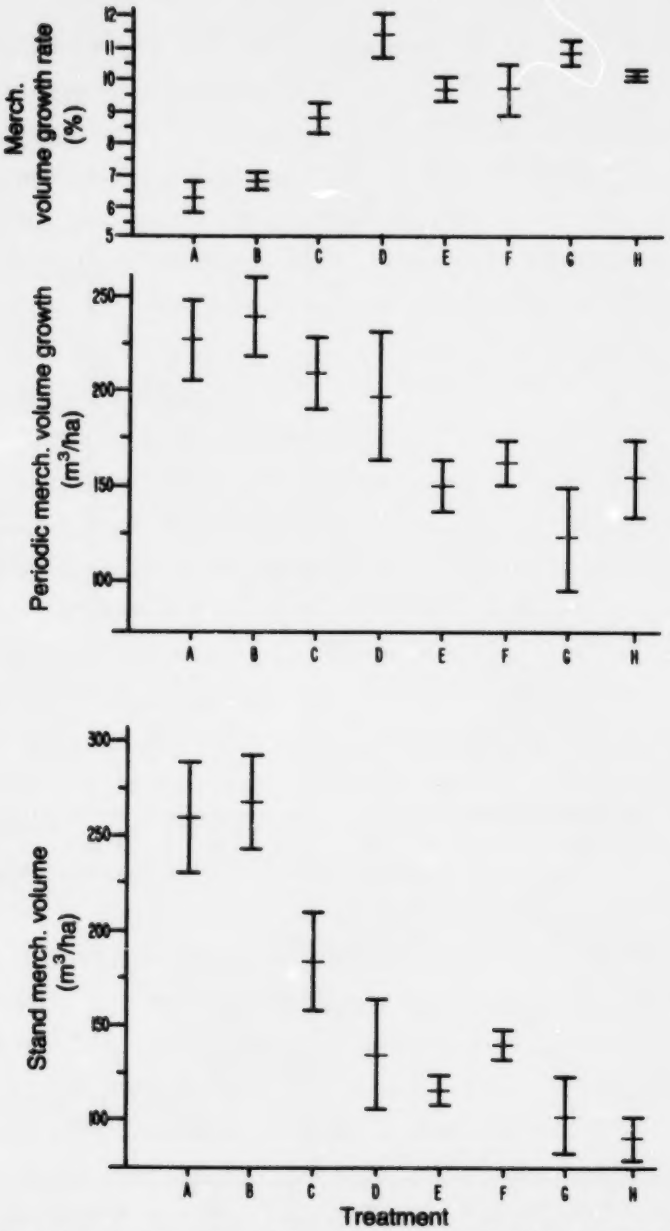

FIGURE 16. Stand net merchantable volume, periodic (1967-1983) merchantable volume growth, and percentage growth rates (with standard errors) by treatment. The percentage growth rates are based on compound interest rates for the period 1978-1983. Each observation is represented as a vertical line segment with the mean at the centre bounded by one standard error.

has not been great enough to offset the decrease in initial growing stock caused by thinning. Thus the merchantable volume per hectare in the thinned plots continues to lag behind that in the control plots (Figure 17).

Mortality

The distribution of the number of stems lost to mortality did not show any clear trends over time or among treatments (Table 7), and the variation in mortality among plots within treatments was high. In general, however, it appears that absolute mortality was lower in the thinned plots.

Comparison of cumulative total and merchantable volume mortality in 1983 indicated that there were no detectable differences among the treatments, although it was greater in the plots with the highest density for the longest period. The treatment means for cumulative merchantable volume mortality were: 5.6, 1.9, 3.2, 5.7, 2.8, 3.1, 2.2, and 1.3 m^3/ha for treatments A to H, respectively.

It was not possible to attribute mortality and damage to specific causes; however, snow breakage (at total age 27 years) and root rot (largely due to Phellinus weirii) were important.

Stand structure

In 1983, the treatment dbh standard deviation means (and standard errors of the treatment means, in parentheses) were: 3.6(0.5), 2.7(0.3), 2.6(0.9), 2.3(0.5), 2.4(0.5), 2.8(0.2), 1.7(0.7), and 1.9(0.5) cm for treatments A to H, respectively. This result suggests that the thinned plots were more uniform in diameter than the control plots; the degree of uniformity increased with greater thinning intensity and frequency (Figure 18).

Crop Trees

Crop trees are those ear-marked for final harvest. In this study, eight crop trees per plot (198 stems per hectare) were chosen on the basis of largest present 1983 diameter.

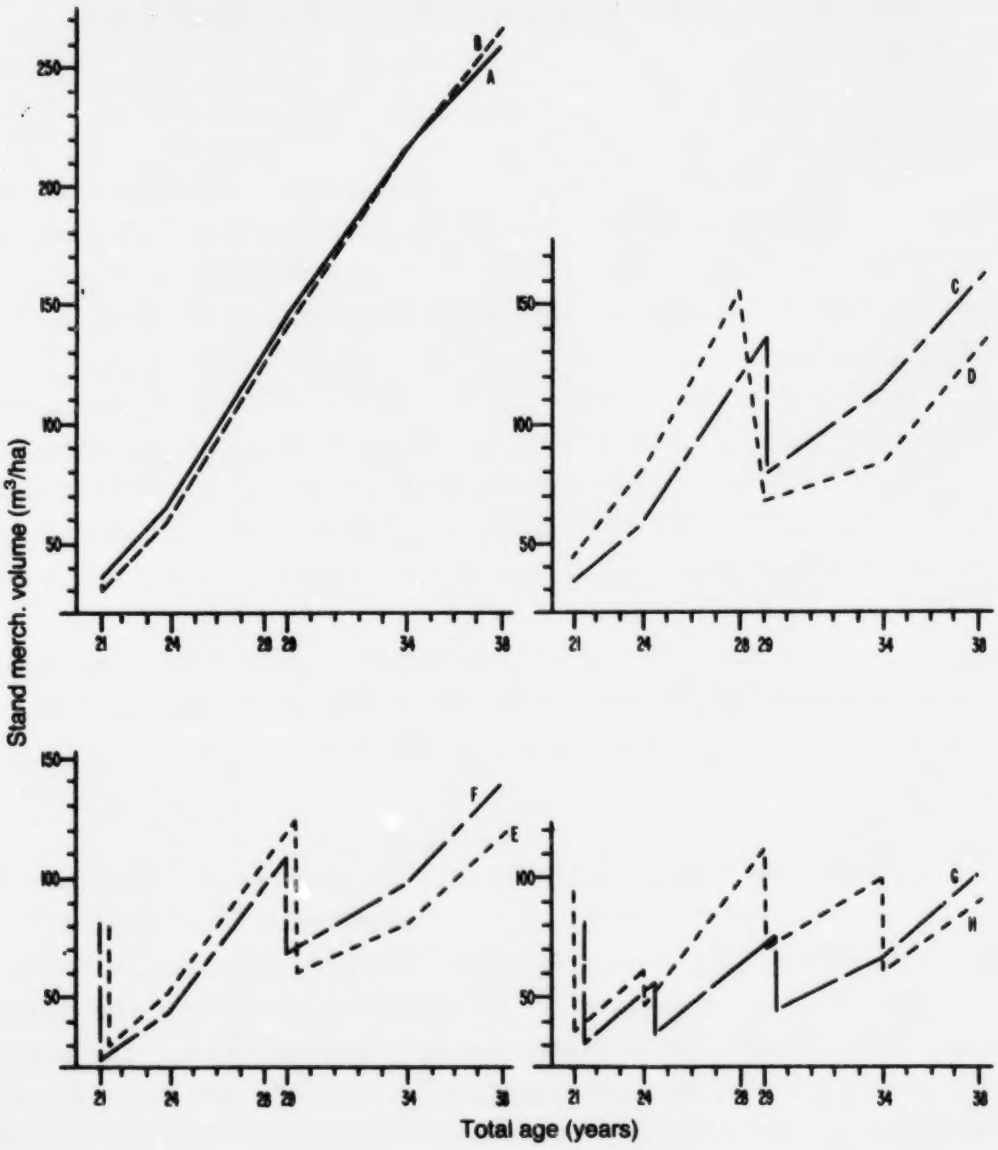

FIGURE 17. Stand net merchantable volume development of all trees from total age 21 years.

TABLE 7. Treatment average mortality (number of stems and diameter)

Treatment	Period								
	1967-83	1967-69		1969-74		1974-79		1978-83	
	Stems (/ha)	Stems (/ha)	QMD[a] (cm)	Stems (/ha)	QMD (cm)	Stems (/ha)	QMD (cm)	Stems (/ha)	QMD (cm)
A	624(34)[b]	43(86)	5.6	389(47)	8.9	80(85)	8.7	111(86)	10.2
B	120(88)	25(200)	8.7	40(75)	8.5	19(195)	12.5	37(68)	11.1
C	315(10)	43(86)	8.8	247(27)	9.2	6(217)	12.7	19(194)	12.8
D	439(96)	50(166)	6.9	352(98)	8.2	37(81)	15.8	0(0)	-
E	49(92)	0(0)	-	25(80)	12.2	25(112)	15.0	0(0)	-
F	50(70)	6(216)	10.4	13(108)	10.2	25(112)	15.6	6(216)	19.5
G	19(126)	6(216)	8.1	0(0)	-	6(216)	18.5	6(216)	17.8
H	37(159)	0(0)	-	6(0)	14.0	31(151)	16.9	0(0)	-

a Quadratic mean diameter at breast height.
b The values in brackets are plot mortality coefficients of variation (%).

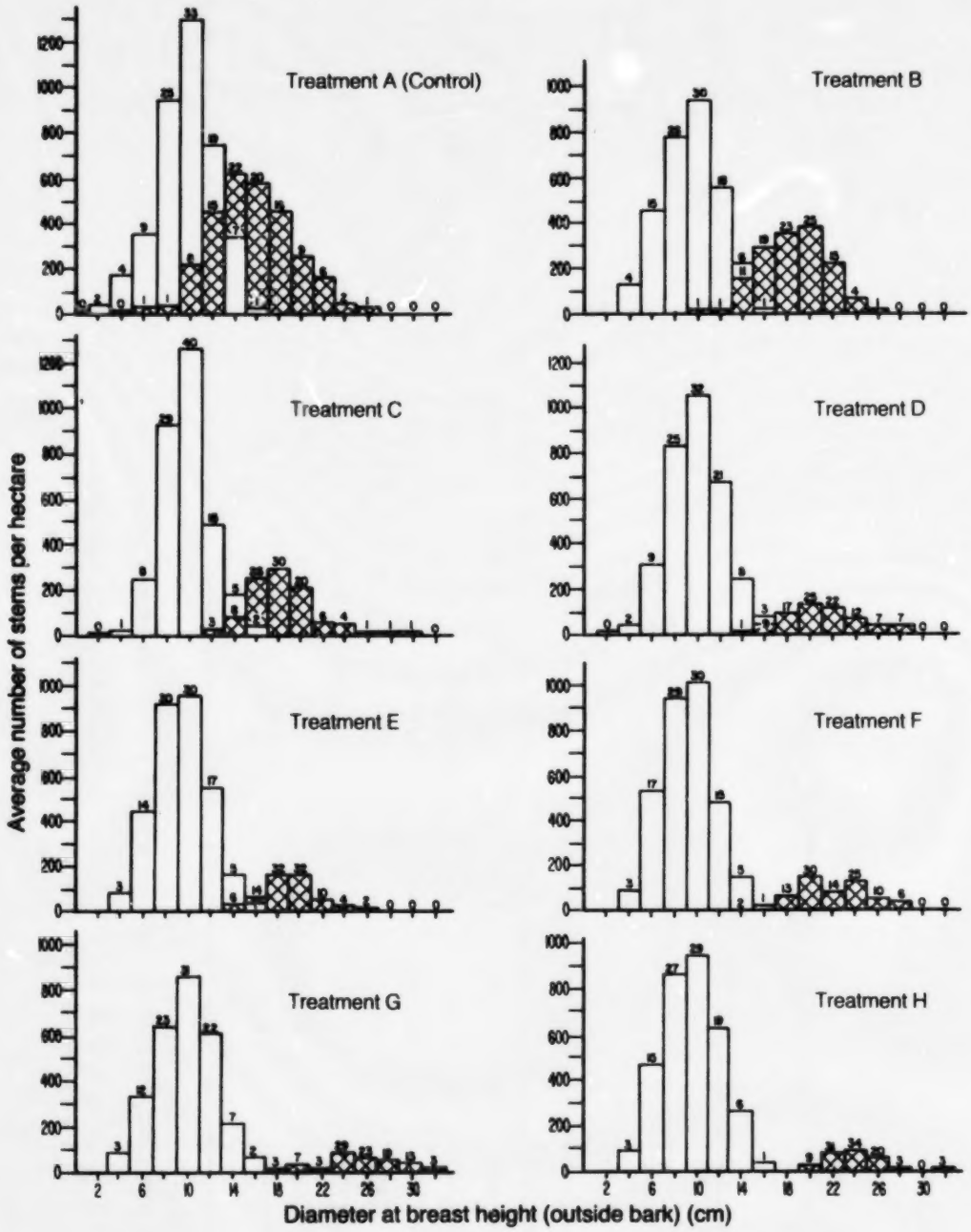

FIGURE 18. Average diameter distribution in 1967 and in 1983. The open bars represent diameter distribution in 1967 and the cross-hatched bars represent diameter distribution in 1983. Numbers above bars are percentage number of stems per hectare.

Crop-tree diameter

In both 1967 and 1983 there were no detectable differences in average or quadratic mean diameter between the control and thinned plots (except treatment G, which in 1983 was detectably higher) (Figure 19). If differences in present (1983) average diameter really do exist, they would be in the range of 5 to 15%. Periodic average or quadratic mean diameter growth in 1967-1983 was detectably higher in the more heavily thinned plots (treatments F to H) (Figure 19).

These results indicate that to date, except in cases where thinning is very heavy and more gradual, precommercial thinning has no important effect on crop-tree diameter and diameter growth.

Crop-tree height

Comparisons of arithmetic average height (AAH) of crop trees in 1967 and 1983 and periodic AAH growth in 1967-83 showed that there were no detectable differences between the control and thinned plots (Figure 20). If differences in present height (height growth) really do exist, they would be in the range of -9 to -3% (-15 to 5%).

These results indicate that to date crop-tree height and height growth are not detectably affected by precommercial thinning.

Crop-tree basal area

The results of the comparisons of crop-tree basal area per hectare are identical to those for crop-tree diameter. In both 1967 and 1983, there were no detectable differences in crop-tree basal area per hectare between the control and thinned plots (except treatment G, which in 1983 was detectably higher) (Figure 20). If differences in present basal area really do exist, they would be in the range of 8 to 31%. Periodic basal area growth in 1967-1983 was detectably higher in the more heavily thinned plots (treatments F to H) (Figure 21).

These results indicate that to date, except in cases where thinning is very heavy and more gradual, precommercial thinning has no important effect on crop-tree basal area and basal area growth.

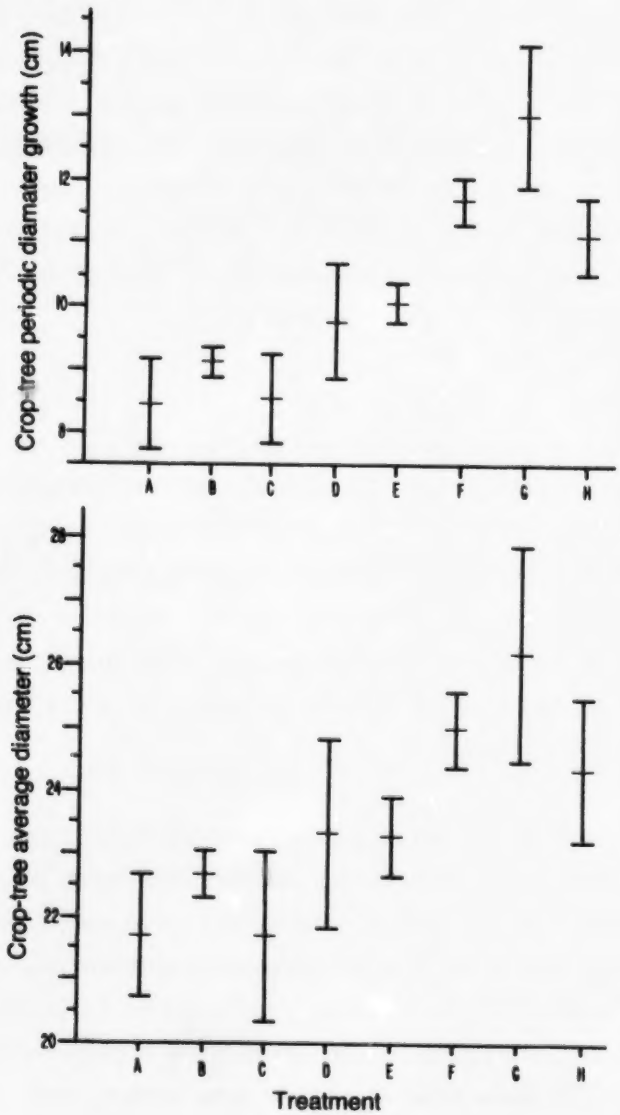

FIGURE 19. Crop-tree arithmetic average diameter and periodic (1967-1983) average diameter growth (with standard errors) by treatment. Each observation is represented as a vertical line segment with the mean at the centre bounded by one standard error.

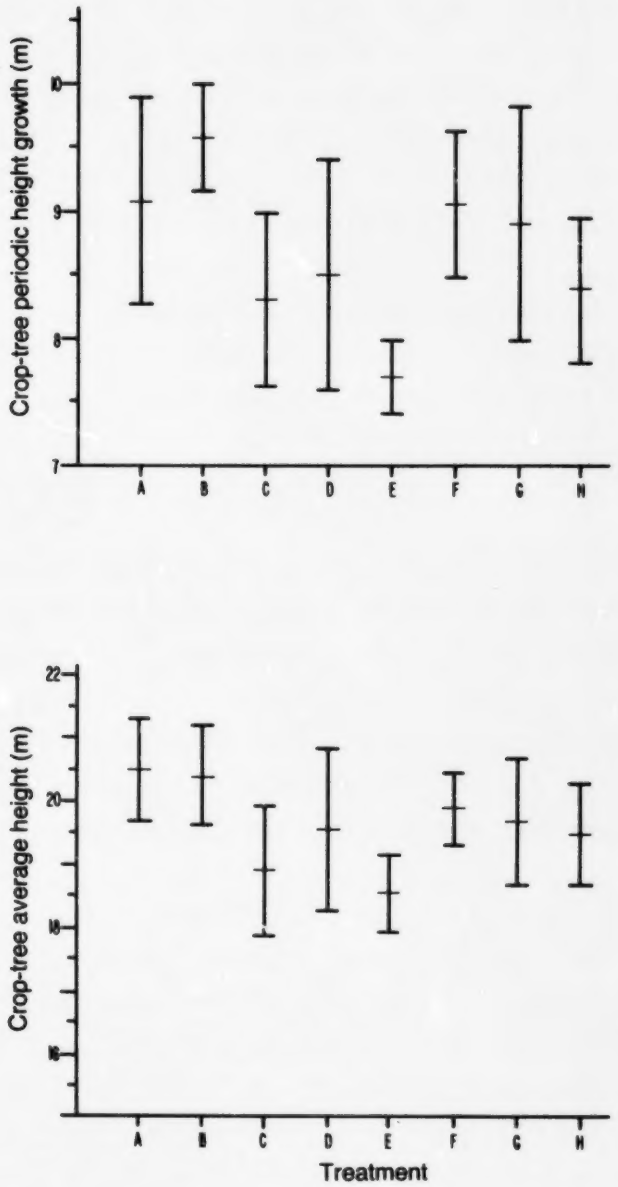

FIGURE 20. Crop-tree arithmetic average height and periodic (1967-1983) average height growth (with standard errors) by treatment. Each observation is represented as a vertical line segment with the mean at the centre bounded by one standard error.

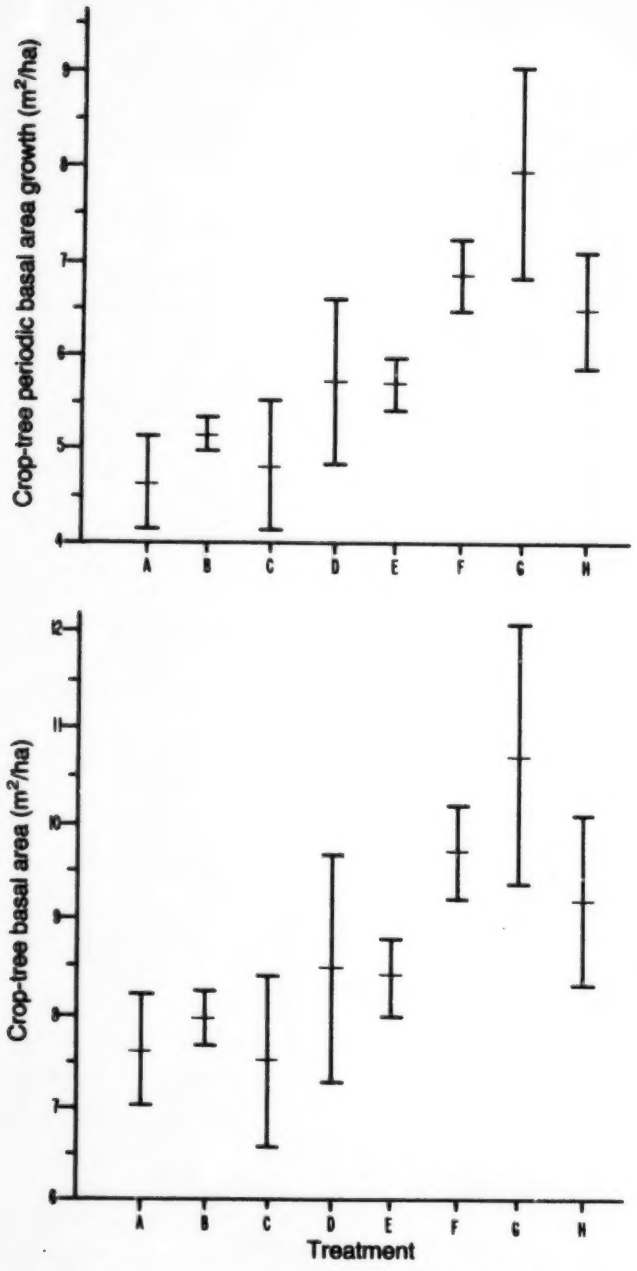

FIGURE 21. Crop-tree basal area and periodic (1967-1983) basal area growth (with standard errors) by treatment. Each observation is represented as a vertical line segment with the mean at the centre bounded by one standard error.

Crop-tree volume

Comparisons of both total and merchantable volumes per hectare in 1967 and 1983 and total and merchantable volume growth in 1967-1983 indicated that there were no detectable differences between the control and thinned plots (except treatment C, which had detectably lower merchantable volume growth) (Figures 22 and 23). If differences really do exist in present total or merchantable volume, they would be in the range of -6 to 42%.

These results indicate that to date precommercial thinning has no important effect on crop-tree total or merchantable volume and volume growth.

DISCUSSION

The precommercial thinning regimes (treatments) investigated in this study differed mainly in thinning intensity -- a combination of thinning frequency (one or more entries) and grade (light or heavy), and timing of first thinning. Thinning intensity varied from no thinning (treatment A) to heavy and frequent thinning (treatment H: four thinning entries, removing a total of 91% of the original stems). As expected, all of the thinning regimes studied have, to varying degrees, shown that thinning promotes growth of residual trees and produces trees of greater merchantable volume.

Gradual heavy thinning resulted in trees with larger diameter and diameter growth. Following thinning, absolute diameter growth was higher in the initially larger trees, but the initially smaller trees gained more on a relative basis. These results agree, at least in their general trend, with studies of Barclay et al. (1982, p. 13) and Oliver and Murray (1983, p. 130).

Although tree height is currently independent of stand (post-thinning) density, individual tree height growth was reduced in the periods following thinning. The reduction in height was related to thinning intensity and the density prior to thinning. A heavy thinning of very dense plots resulted in a larger reduction in height compared to a light thinning of similarly dense plots or a heavy thinning of less dense plots. This reduction in height

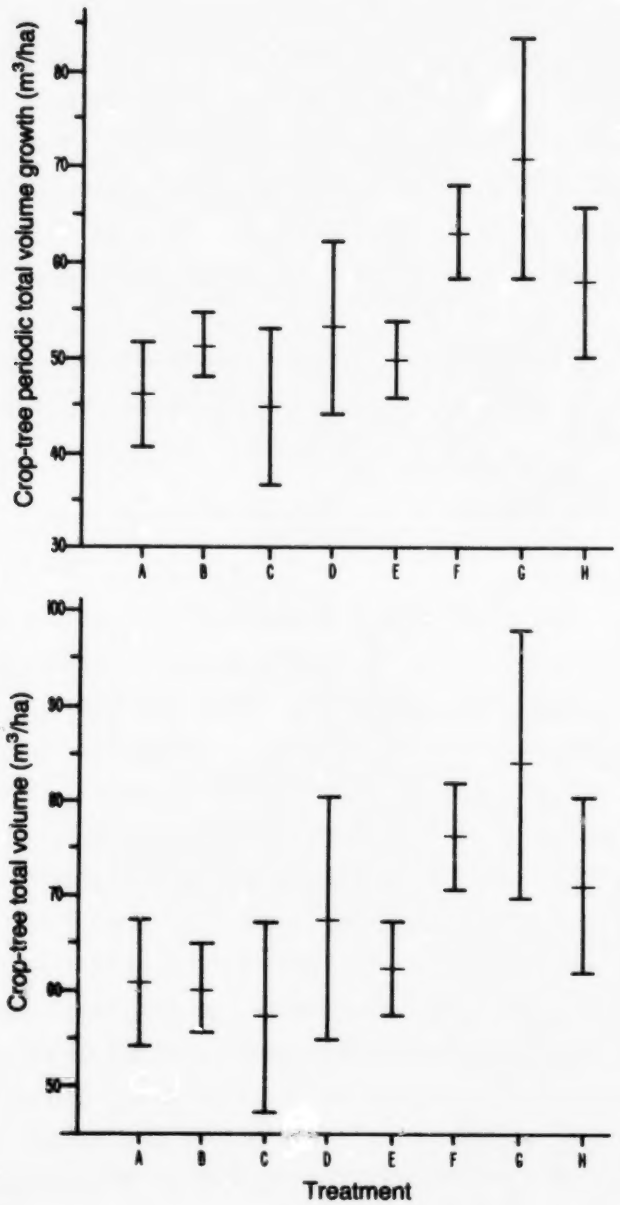

FIGURE 22. Crop-tree total volume and periodic (1967-1983) total volume growth (with standard errors) by treatment. Each observation is represented as a vertical line segment with the mean at the centre bounded by one standard error.

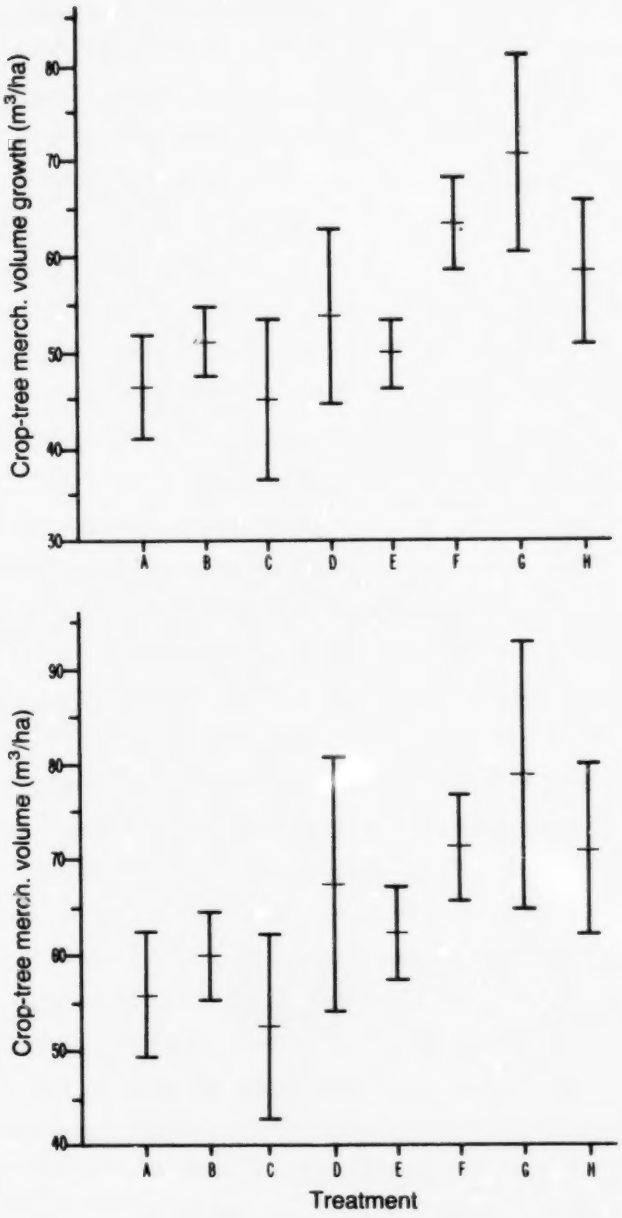

FIGURE 23. Crop-tree merchantable volume and periodic (1967-1983) merchantable volume growth (with standard errors) by treatment. Each observation is represented as a vertical line segment with the mean at the centre bounded by one standard error.

growth following thinning -- called "thinning shock" (Staebler 1956) -- has been reported and discussed by Harrington and Reukema (1983) and some of the references cited therein. It appears, though, that the trees do recover from this shock and may respond positively to thinning (Figure 8), an observation also noted by Barclay et al. (1982, p. 13) and Harrington and Reukema (1983, p. 41). As well, if the present height growth trends (Figure 8) continue, individual tree height will no longer be independent of stand density.

On a land area basis, gradual heavy thinning resulted in greater stand average diameter and diameter growth, for the entire stand and for crop trees. The differences in stand average diameter among the treatments were less in crop trees than in the entire stand. Similar conclusions, but of different magnitude, were reported by Tappeiner et al. (1982). On a crop-tree or entire-stand basis, thinning did not affect average height. This means that, for the entire stand or crop trees in the range of post-thinning densities covered by the thinned plots, height or height growth was independent of density, as also reported by Tappeiner et al. (1982). Omule (1984) reported that crop-tree height, unlike the entire-stand height, was not greatly affected by a decrease in density on a medium-to-good site.

Unlike stand diameter or height, standing and net (standing plus thinned) basal area and total and merchantable volume per hectare were reduced by heavy thinning. Basal area and volume per tree, however, increased as a result of thinning and with increase in thinning intensity. These results generally agree in trend with those reported elsewhere (e.g., Warrack 1979; Hall et al. 1980; Barclay et al. 1982; Tappeiner et al. 1982; Harrington and Reukema 1983; Oliver and Murray 1983; Omule 1984). To date, crop-tree basal area, and total and merchantable volumes were not detectably affected by thinning, although competition before plot establishment might possibly have confounded these effects. If the target crop-tree density is 198 stems per hectare, then this current lack of effect of thinning on crop trees offers some flexibility in planning precommercial thinning operations.

Thus, on the average, trees in thinned plots were larger in diameter and and slightly taller, and grew faster in diameter than trees in unthinned plots. Furthermore, trees in gradually heavily thinned plots were more

uniform in diameter and produced more merchantable volume than trees in lightly thinned or unthinned plots. Mortality was less in the thinned plots than in the unthinned plots, probably because the mortality that would have occurred in the thinned plots was removed in thinnings. Thus, if favourable net returns could be obtained from precommercial thinnings -- and assuming greater premiums are associated with larger tree dimensions, then the thinned plots had more value than the unthinned plots. Tree form and branch characteristics, important considerations in the value of the heavily thinned plots, were not studied.

Comparison of the effects of very heavy suppression (treatment D), heavy suppression (treatment E), and light suppression (treatment F) on individual tree and stand responses to subsequent thinning indicated that the different degrees of suppression did not significantly affect tree and stand development following the final thinning. This similarity in response to thinnings following various grades of suppression shows the flexibility of the timing of the first and subsequent thinning entries. The plots can be thinned frequently at 7- to 15-year intervals (before total age 30 years) to the same post-thinning density without affecting tree or stand development. Omule (1984), however, observed that heavy early suppression reduced the ability of a stand to respond to subsequent thinning. The differences in these studies is probably due to the differences in time at which the various plots were subject to suppression, before thinning: the plots in this study were left unthinned for about 8 years, compared to 29 years for the study previously reported by Omule (1984).

The observations made in this study were based on a series of 0.04-ha plots, which are relatively very small. One obvious disadvantage was the inability to effectively study diameter distributions. Another disadvantage is that if this experiment is carried on to rotation age (possibly another 30 years from now), there likely will not be a sufficient number of survivor trees, particularly in the most heavily thinned plots, to enable meaningful analyses on a stand basis. Furthermore, Curtis (1983) indicated that small plot sizes are generally undesirable for growth and yield purposes. The observations made in this study to date, however, appear reasonable in terms of the expected general trends of the effects of thinning on stand and tree development.

CONCLUSIONS

The range of thinning treatments and conditions in this study indicated that:

1. Thinning in general resulted in larger diameter and diameter growth on an individual tree and entire stand basis; heavy and gradual thinning resulted in larger values than did light and "one-shot" thinning.
2. Absolute diameter growth was higher in initially larger diameter trees; however, on a percentage basis, the smaller diameter trees gained more from thinning.
3. Thinning did not affect height or height growth, on an individual tree, entire stand, or crop-tree basis.
4. Height growth, immediately following thinning, was substantially reduced -- a sign of thinning shock -- but the growth is now currently higher in the more heavily thinned plots.
5. Standing and net (standing plus thinned) basal area, and total and merchantable volume per hectare were reduced by heavy thinning. Basal area or volume per tree, however, increased as a result of thinning and with increase in thinning intensity. Thinning resulted in merchantable volume per tree gains over the control, ranging from 65 to 250% compared to no thinning.
6. To date, crop-tree diameter, basal area, and total and merchantable volumes were not affected by thinning (except in cases where thinning was very heavy).
7. Gradual heavy thinning resulted in trees with more total merchantable volume, although the volume per hectare was substantially lower, compared to that resulting from light or less gradual thinning.
8. Mortality was generally lower in the thinned plots; however, there were no clear trends in mortality among the thinning treatments, or over time.

The above conclusions, although based on the study of thinning regimes not designed for specific practical use, clearly and empirically demonstrate the benefits of thinning. Furthermore, actual response values have been obtained

for conditions specific to this study, some of which can be used to evaluate current operational thinning prescriptions. In addition, the data collected to date are useful for the calibration of growth simulation models such as the Tree and Stand Simulation (TASS) model (Mitchell 1975), to facilitate comparisons of stand density management regimes and construction of managed stand yield tables.

RECOMMENDATIONS

Based upon the results to date, the following recommendations are made regarding precommercial thinning of dense, young, coastal Douglas-fir stands under 30 years total age on medium moist, medium rich sites (site index 25 to 33 m at 50 years total age using Bruce's [1981] site index curves) in the Wetter Maritime Coastal Douglas-fir Subzone in British Columbia:

1. Low thinnings, favouring larger and healthier trees, are recommended.
2. If the favourable growth trends observed in the lower post-thinning densities in this study will continue to rotation, then gradual thinnings to post-thinning densities of under 1000 stems per hectare, similar to treatments F, G, and H, would be optimal for sawlog production.

The decision to thin, however, depends upon the consideration of several factors, such as the economics of precommercial thinning and the need for additional stand tending practices such as pruning, most of which have not been considered in this study at this stage. Further studies are needed to evaluate the practicality of repeated precommercial thinning regimes relative to their biological benefits, and to explore future (commercial) thinning options. Furthermore, in order to verify and expand the conclusions to date, and to provide more complete plot histories -- valuable in growth model calibration, continued maintenance and remeasurement of the experiment to rotation age is recommended. As well, studies involving the effects of thinning on wood quality should be incorporated into the experiment.

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APPENDIX 1. Comparisons of treatment means for the various individual tree, entire stand, and crop-tree characteristics

1. Individual tree diameters (covariance-adjusted means)

Diameter class	Parameter	Treatments[a]
10	1983 diameter	H G F E D B C A
	Periodic growth 1967-1983	H G F E D B C A
	Periodic growth 1978-1983	H G E D F C B A
12	1983 diameter	G H F E D B C A
	Periodic growth 1967-1983	G H F E D B C A
	Periodic growth 1978-1983	G H D F E C B A
14	1983 diameter	G F H E D B C A
	Periodic growth 1967-1983	G F H E D B C A
	Periodic growth 1978-1983	G F H D E C B A
16	1983 diameter	N.S.[b]
	Periodic growth 1967-1983	N.S.
	Periodic growth 1978-1983	N.S.

2. Entire stand

	Stand basal area (m^2/ha)
1967 standing:	D C A H B E G F
1983 standing:	A B C F D E G H
1983 standing and thinnings:	D C A B H E F G
1983 cumulative mortality:	A D C E F B G H
Net growth (incl. thin) 1967-1983:	B A C D F E H G

APPENDIX 1 (Cont'd)

Stand basal area (m^2/ha)	Treatments[a]
Gross growth 1967-1983:	B A C D F E H G
% net growth rate 1967-1983:	F B G E H A C D
% net growth rate 1978-1983:	D G H E F C B A
Basal area per tree 1967: (m^2)	G F H B E D C A
Basal area per tree 1983: (m^2)	G H F D E B C A
Stand total volume (m^3/ha)	
1967 standing:	D C A H B E G F
1983 standing:	A B C F D E G H
1983 standing and thinnings:	A D B C H E F G
1983 cumulative mortality:	N.S.[b]
Net growth (incl. thin) 1967-1983:	B A D C F E H G
Gross growth 1967-1983:	A B D C F E H G
Stand total volume (m^3/ha)	
% net growth rate 1967-1983:	B F A E G H C D
% net growth rate 1978-1983:	G D H F E C B A
Volume per tree 1967: (m^3)	G H F B E D A C
Volume per tree 1983: (m^3)	G H F D E B C A

APPENDIX 1 (Cont'd)

Stand merchantable volume (m^3/ha) (Total volume less a 30-cm stump and a 10-cm diameter inside bark top)

1967 standing:	D H A C B G E F
1983 standing:	B A C F D E G H
1983 standing and thinnings:	B A D C H F E G
1983 cumulative mortality:	N.S.[b]
Net growth (incl. thin) 1967-1983:	B A D C F H E G
Gross growth 1967-1983:	B A D C F H E G
% net growth rate 67-83:	B A F C E D H G
% net growth rate 78-83:	D G H E F C B A
Merch. volume per tree 1967:	G F H B E D A C
Merch. volume per tree 1983:	G H F D E B C A

Quadratic mean diameter

1967:	G F H B E D C A
1983:	G H F D E B C A
Net growth 1967-1983:	G H D F E C B A

Arithmetic average diameter

1967:	G F H B E D C A
1983:	G H F D E B C A
Net growth 1967-1983:	G H D F E C B A

Arithmetic average height

1967:	G H B F E D C A
1983:	G H D F B E C A
Growth 1967-1983:	N.S.

APPENDIX 1 (Cont'd)

3. Crop trees

Crop-tree diameter	Treatments[a]
1983:	G F H E D B C A
Growth 1967-1983:	G F H E D B C A
Crop-tree height	
1983:	N.S.[b]
Growth 1967-1983:	N.S.
Crop-tree basal area	
1983:	G F H D E B C A
Growth 1967-1983:	G F H E D B C A
Crop-tree total volume	
1983:	N.S.
Growth 1967-1983:	N.S.
Crop-tree merchantable volume	
1983:	N.S.
Growth 1967-1983:	G F H D B E A C

[a] The treatments are arranged in descending order of means. Treatments underscored by the same line are not detectably different at p = .05, using repeated t-test procedure for individual tree comparisons and Tukey's procedure for the entire stand and crop-tree comparisons (SAS Institute Inc., 1982, pp. 169-175).

[b] N.S. means not detectably different at p = .05.

APPENDIX 2. A summary of stand and crop-tree characteristics in 1983 (total age 38 years)

Treatment	Year----1948 (Age[b])---(2)	1966 (21)	1969 (24)	1974 (29)	1979 (34)	1983 (38)	?	Final post-thinning density	Characteristics in 1983 for standing trees: Entire stand: Stem count	Ave. dia.	Ave. ht.	Basal area	Total vol.	Merch. vol.	Crop-trees[a]: Ave. dia.	Ave. ht.	Basal area	Total vol.	Merch. vol.
	Nominal density (trees per hectare)								(/ha)	(cm)	(m)	m^2/ha	m^3/ha	m^3/ha	(cm)	(m)	(m^2/ha)	m^3/ha	m^3/ha
A	3000	----------						3000	2883	14.9	17.0	44.9	338.3	259.5	21.7	20.5	7.4	60.7	55.6
B	3000	1500	----------					1500	1462	18.3	18.4	40.4	310.0	267.8	22.7	20.4	8.0	64.9	60.0
C	3000			1000	----------			1000	981	18.0	17.2	25.8	187.3	160.6	21.7	18.9	7.5	57.2	52.4
D	3000			500	----------			500	512	21.2	18.8	18.6	144.2	131.4	23.3	19.6	8.5	67.5	67.5
E	3000	1500		500	----------			500	499	21.0	17.7	17.9	128.5	116.6	23.3	18.6	8.4	62.5	62.5
F	3000	1000		500	----------			500	518	22.1	18.7	20.2	152.2	139.8	25.0	19.9	9.7	76.1	71.4
G	3000	1000	500	250	----------			250	254	25.6	19.5	13.8	107.0	100.7	26.2	19.7	10.8	83.6	78.9
H	3000	1500	1000	500	250	----------		250	288	23.5	19.3	12.7	97.3	90.5	24.3	19.5	9.2	71.3	71.3
I[c]	3000		1500	1000	500	250----------		250	253	22.7	20.0	10.4	84.7	78.3	24.0	20.8	9.1	75.2	70.2
J[c]	3000			1500	1000	500	250--------	250	525	19.5	18.7	16.0	124.0	110.0	22.3	20.1	7.8	63.1	58.2

[a] Eight trees per 0.0405-ha plot (or 198 trees/ha).
[b] Total age from seed (years).
[c] These treatments were not analysed in this report.